PERFORMANCE ENHANCEMENT OF ULTRA WIDEBAND WPAN USING NARROWBAND INTERFERENCE MITIGATION TECHNIQUES

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ABSTRACT

A new promising technique adopted by 4G community is ultra-wideband technology, which offers a solution for high bandwidth, high data rate, low cost, low power consumption, position location capability etc. A conventional type of UWB communication is impulse radio, where very short transient pulses are transmitted rather than a modulated carrier. Consequently, the spectrum is spread over several GHz, complying with the definition of UWB. Currently, the Rake receiver used for spread spectrum is considered a very promising candidate for UWB reception, due to its capability of collecting multipath components. Since UWB signals occupy such a large bandwidth, they operate as an overlay system with other existing narrowband (NB) radio systems overlapping with their bands. In order to ensure a robust communication link, the issue of coexistence and interference of UWB systems with current indoor wireless systems must be considered. Ultra Wideband technology with its application, advantages and disadvantages are discussed in detail. Design of UWB short pulse and a detail study IEEE 802.15.3a UWB channel models statistical characteristics have been analyzed through simulation. Simulation studies are performed and improved techniques are suggested for interference reduction in both Impulse Radio based UWB and Transmitted Reference type of UWB system. Modified TR-UWB receiver with UWB pulse design at transmitter end and notch filtering at receiver's front end proved to be more efficient in single NBI, multiple NBI and WBI suppression. Extensive simulation studies to support the efficacy of the proposed schemes are carried out in the MATLAB. Bit error rate (BER) performance study for different data rates over different UWB channel models are also analyzed using proposed receiver models. Performance improvement of TR-UWB system is noticed using the proposed techniques.

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CERTIFICATE

This is to certify that the thesis entitled "**Performance Enhancement of Ultra Wideband WPAN using narrowband interference mitigation techniques**" submitted by **Mr. Bikramaditya Das**, in partial fulfillment of the requirements for the award of Master of Technology (Research) in Electrical Engineering, with specialization in **'Electronics System and Communication'** at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter presented in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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I dedicate this thesis to my family and friends.

Bikramaditya Das

CONTENTS

LIST OF ACRONYMS

AWGN	Additive White Gaussian Noise
AcR	Auto correlation Receiver
ARake	All-Rake
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CIR	Channel Impulse Response
CSI	Channel State Information
DFE	Decision Feedback Equalizer
DSP	Digital Signal Processing
EMC	Electromagnetic Compatibility
FCC	Federal Communication Commission
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
HDTV	High Definition Television
IF	Intermediate Frequency
IR	Impulse Radio
ISI	Inter Symbol Interference
LAN	Local Area Network
LE	Linear Equalizer
LOS	Line of Sight
MB-OFDM	Multiband Orthogonal Frequency Division Multiplexing
MMSE	Minimum Mean Square Error
m-NBI	Multiple Narrowband Interference
NBI	Narrowband Interference
NIC	Network Interface Card
NLOS	Non- Line of Sight
OFDM	Orthogonal Frequency Division Multiplexing
PCI	Peripheral Component Interconnect
PRake	Partial Rake

PSD	Power Spectral Density
RRC	Root Raised Cosine
SIR	Signal to Interference Ratio
S–V	Saleh-Valenzuela
SNR	Signal to Noise Ratio
SRake	Selective Rake
STOBC	Space-time orthogonal block coding
TGs	Task groups
TR	Transmitted Reference
UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wideband
WBI	Wideband Interference
WG	Working group
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WUSB	Wireless universal serial bus

LIST OF SYMBOLS

B_f	Fractional Bandwidth
t_0	Time offset
X	Lognormal shadowing term
Λ	Cluster arrival rate
Γ	Cluster decay factor
σ_x	Standard deviation of lognormal shadowing term
$\alpha_{k,l}$	Multipath gain coefficients
τ_m	Mean excess delay (nsec)
τ_{rms}	RMS delay (nsec)
T_s	Symbol duration
α	Roll-off Factor
$p(t)$	UWB pulse
$i(t)$	Received interferer signal
$n(t)$	Additive White Gaussian Noise
H	Hermitian Toeplitz matrix
D_j	Delay hopping code
$p(-t)$	Receiver matched filter
P_l	Average Transmit Power of the Narrowband waveform

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Chapter 1

Introduction

INTRODUCTION

1.1 Introduction

In the recent years, short-range wireless applications and ad-hoc networking have become increasingly important in line with the vision to achieve ubiquitous communications. Due to the convergence of wireless connectivity, the next generation of the wireless world will most likely be an integration of heterogeneous networks including wireless regional area networks (WRAN), wireless wide area networks (WWAN), wireless metropolitan area networks (WMAN), wireless local area networks (WLAN), and wireless personal area networks (WPAN). Ultra-wideband (UWB) radio is an emerging technology in WPAN wireless systems that has attracted a great deal of interest from academia, industries, and global standardization bodies. The IEEE 802.15.3a (TG3a) and IEEE 802.15.4a (TG4a) are two task groups (TGs) within 802.15 working group (WG) that develop their standards based on UWB technology. UWB technology has been around since 1960, when it was mainly used for radar and military applications. Recent advances in silicon process and switching speeds are moving it into the commercial domain. One of the most promising commercial application areas for UWB technology is the very high data rate wireless connectivity of different home electronic devices at low cost and low power consumption. Ultra-wideband technology offers a solution for sharing the bandwidth resource and physical size requirements of next-generation consumer electronic devices. In addition, UWB promises low susceptibility to multipath fading, high transmission security and simple design.

There are two main differences between UWB and other narrowband or wideband systems. First, the bandwidth of UWB systems, as defined by the Federal Communications Commission (FCC) is more than 25% of a center frequency or more than 1.5GHz. Clearly, this bandwidth is much greater than the bandwidth used by any current technology for communication. Second, UWB is implemented in a carrier less fashion. UWB transmissions can transmit information by generating radio energy at specific time instants and occupying large bandwidth thus enabling a pulse position or time modulation. Information can also be modulated on UWB pulses by encoding the polarity of the pulse, and/or also by using orthogonal pulses. Conventional narrowband and wideband systems use Radio Frequency (RF) carriers to move the signal in the frequency domain from baseband to the actual carrier frequency where the system is allowed to operate. Conversely, UWB implementations can directly modulate an impulse that has a very sharp rise and fall time. The extremely short duration of UWB pulses spreads their energy across a wide range of frequencies i.e. several GHz. Due to the extremely low emission levels currently allowed by regulatory agencies, UWB systems tend to be short-range and indoors applications. However, due to the short duration of the UWB pulses, it is easier to engineer extremely high data rates, and data rate can be readily traded for range by simply aggregating pulse energy per data bit using either simple integration or by coding techniques. One of the important advantages of UWB systems is their inherent robustness to multi-path fading. Multipath fading results from the destructive interference caused by the sum of several received paths that may be out of phase with each other. The very narrow pulses of UWB waveforms result in the multiple reflections caused by the channel being resolved independently rather than combining destructively at the receiver. As a result, the time-varying fading that affects narrowband systems is significantly reduced by the nature of the UWB waveform.

One of the important considerations for the success of UWB systems is the compatibility and coexistence of such systems with other WLANs or WPANs. The ultrawide bandwidth cannot be assigned exclusively to UWB signals and overlapping with the bands of many other narrowband systems arise. In order to ensure a robust communication link, the issue of coexistence and interference of UWB systems with current indoor wireless systems must be considered. Due to the wideband nature of UWB emissions, it could potentially interfere with other licensed bands in the frequency domain if left unregulated. Industry's first commercial UWB standard employs unlicensed 3.1 − 10.6 GHz authorized by US's Federal Communications Commission (FCC). The assessment of mutual interference between UWB devices and existing narrowband systems during overlay is important to guarantee no conflicting coexistence and to gain worldwide acceptance of UWB technology. Hence, various technical challenges remain as open issues, which need to be confronted to ensure the successful deployment of this upcoming technology.

This chapter begins with an exposition of the principal motivation behind the work undertaken in the thesis, followed by literature survey in section 1.3. The contributions and layout of the thesis are discussed in section 1.4.

1.2 Motivation for Work

Short-range communication is likely to be mainstream field of research for the next decade. As a license exempt technology, UWB can be used for numerous commercial and military applications, including ranging, sensing, low range networking and multimedia consumer products. UWB communications offer a promising solution to an increasingly overcrowded frequency spectrum as its strength lies in the use of extremely large transmission bandwidths. Since UWB signals occupy such a large bandwidth, they operate as an overlay system with other existing narrowband (NB) radio systems. For an example, if UWB is to be used in Personal Area Network (PAN) in close proximity to an 802.11a Local Area Network (LAN), then it must be designed in a manner to peacefully coexist with the LAN. Hence, UWB systems will most likely suffer from interference concerns from other narrowband and wideband consumption systems in such type of overlay environment. For a flexible solution, these interferers should be suppressed only on an as-needed basis. A proper interference mitigation technique is essential to a successful UWB receiver design and is a subject of potential research.

Hence, of UWB systems, it is important to assess the potential coexistence of impulse radio (IR) UWB systems with existing and next generation wireless systems. Coexistence requires that both NB and UWB systems does not interfere with one another. UWB devices must be designed to account for two fundamental aspects: these must not cause harmful interference to licensed next generation wireless services and existing NB systems (e.g., GPS, GSM/GPRS, UMTS, Bluetooth, IEEE 802.11 WLAN, etc.) UWB devices must be robust and must able to operate in the presence of interference caused by both NB systems and other UWB-based nodes. Although the individual UWB device must satisfy emission limits imposed by regulatory agencies, the cumulative interference from multiple UWB emitters is not regulated. The impact of such aggregate interference on victim NB systems, as well as on other UWB systems, can be significant. Moreover, the transmitted-reference UWB receivers have become very popular for their simplicity and robust performance in multipath channels. However, their performance is limited by various types of channel noise such as additive white Gaussian noise or narrowband interference and wideband interferences on the transmitted signal. Thus, the study of the impact of these interferers on UWB WPAN systems and devising techniques which can mitigate such interferers efficiently by maximizing the extraction of information from reference pulses for TR-UWB type receivers are essential to enhance the performance of the system.

1.3 Literature Survey

UWB communications was first employed by G Marconi in 1901 to transmit Morse code sequences across the Atlantic Ocean using spark gap radio transmitters. However, the benefit of a large bandwidth and the capability of implementing multi-user systems provided by electromagnetic pulses were never considered at that time [1]. Approximately 50 years after G. Marconi, modern pulse based transmission gained momentum in military applications in the form of impulse radars. The first wave of UWB was studied when James Clark Maxwell had proposed the electromagnetic theory at the end of 19th century. During the period 1960’s to 1990's, UWB research from many researchers and laboratories, focused on radar and highly secure communications [1]. A significant difference between traditional radio transmissions and UWB radio transmissions is that traditional systems transmit data by varying the power level, frequency, and/or phase whereas UWB system transmit data by generating radio energy which occupies large bandwidth at a specific time instant using pulse-position or time-modulation. UWB has focused on radar, sensing and military communications [2] and [3]. In 1993, H.F.Engler wrote prolifically on the electromagnetic of UWB about the area of high-power baseband pulse radiation, the new methods for generation and radiation of Ultrawideband signals [4]. M. Ressler, L.Happ, L.Nguyen, Ton Tuan and M.Bennett discussed the basic phenomenology of impulse radar, specifically the propagation effects of targets [5]. Ultra-wide bandwidth signal propagation experiment in a rural terrain to characterize the outdoor UWB signal propagation channel is indicated in [6], [7], [8] and [9]. In [10] and [11], the UWB research focused more on communication methodology and commercial short-range wireless applications such as wireless LAN and home entertainment. Some general properties of ultra-wideband (UWB) communications systems such as the importance of fractional bandwidth in ultra-wideband pulse design and identifying the characteristics of UWB technology in order to make it an attractive solution for indoor wireless networks is discussed in [12], [13] and [14]. D. Cassioli, M.Z. Win and A.F. Molisch first applied a statistical model for the UWB indoor channel. The main goal of this work was to develop an understanding of the indoor UWB propagation channel, including the time-of-arrival, angle-of-arrival and level distributions of a collection of received signals [15]. They concluded that the power delay profile can be well modeled by a single exponential decay with a statistically distributed decay-time constant.

Federal Communications Commission (FCC) declared the unlicensed use of UWB within the frequency range of 3.1–10.6 GHz and fixed the emission power level as -41.3 dBm/MHz in 14 February 2002 Report and Order [16]. This is intended to provide an efficient use of scarce radio bandwidth while enabling both high data rate personal area network (PAN) wireless connectivity and longer-range, low data rate applications as well as radar and imaging systems. For UWB systems, the transmitted power is much less and is of the order 0.5 mW. The FCC defined UWB signal as those which have a fractional bandwidth greater than 0.20 or a bandwidth greater than 500 MHz measured at -10 dB points [17] and [18]. A sub-committee was formed to establish the path loss model and multipath characteristics of typical environments where IEEE 802.15.3a devices operate [19]. The main purpose of this path loss model is to compare the different physical layer proposals at the target operating distances [20] and [21].

J.F.M. Gerrits and JR.Farserotu [22] presented ultra wideband (UWB) transceivers based on impulse-radio (IR) technology. In IR-UWB system, low complexity Rake reception technique is generally used as suboptimal receivers due to their fine delay resolution [23] and [24]. RAKE-MMSE combining is designed to counter the effects of multipath fading by using the advantages of fingers of Rake receiver and taps of MMSE equalizer. Each finger and tap independently decodes a single multipath component; at a later stage the contribution are combined in order to make the most use of the different transmission characteristics of each transmission path [25], [26], [27], [28], [29] and [30]. Transmitted-reference (TR) ultra-wideband (UWB) wireless communication systems relax the complicated UWB timing synchronization requirements and can provide a simple receiver that gathers the energy from the many resolvable multipath components [31], [32], [33], [34] and [35].

UWB technology focuses many challenges and difficulties despite of its advantages and widespread acceptance. Due to overlay of UWB and narrowband signals in frequency spectrum, the presence of narrowband interference in UWB communication system is an unavoidable problem. Interference is one of the major challenges in the design of UWB communication systems since it occupies a large frequency spectrum. Coexisting users of UWB wireless personal area networks (WPAN) include Bluetooth, IEEE 802.11a WLAN devices (5.150–5.825 GHz) and industrial (2.4 GHz), scientific, and medical (ISM) band devices [36], [37], [38] and [39]. UWB signals suffer from inter symbol interference (ISI) for high data rate WPAN system [40]. Developing modification techniques to provide immunity to NBI, WBI etc. is one of the key issues of UWB research. Pulse shaping and different receiver techniques are used for suppressing interference. The Transmitted-Reference (TR) signaling scheme in conjunction with the auto-correlation receiver (AcR) is low-complexity system architecture for Ultra Wide Band (UWB) communications [41] and [42]. Using a notch filter at UWB receiver NBI can be suppressed [43], [44], [45], [46], [47] and [48]. Suppression of interference few techniques like pulse design method using wavelet is analyzed by Lloyd Emmanuel, Xavier N.Fernando [49].

More recently, UWB systems have been targeted at very high data rate applications over short distances, such as USB replacement, as well as very low data rate applications over longer distances, such as sensors and RF tags [49].

1.4 Objective and Outline of Thesis

UWB signal spreads over a large bandwidth of several gigahertz and hence coexists with other narrowband systems. Thus it may cope with the narrowband interference (NBI) using their high processing gain. However, due to low transmission power, it is anticipated that even this large processing gain is not sufficient to suppress high levels of NBI. In many cases, the power of NBI is a few tens of dBs higher than both the signal and noise power. Hence, if such interference is not suppressed properly, the UWB receiver may be jammed and the system performance degrades. Investigation of UWB system using realistic channel models is to be carried out of performance improvement through interference suppression. NBI suppression techniques using Rake receiver based on the minimum mean square error (MMSE) criterion for UWB system needs to be analysed. Transmitted-Reference (TR) signaling, in conjunction with an autocorrelation receiver (AcR) offers a low complexity alternative to Rake reception. This research work has demonstrated and analyzed the performance of TR systems with modified AcR in cancelling single NBI, multiple NBI and wideband interference (WBI) altogether. Extensive simulation studies are carried out and performance are analyzed to prove the potentials of the proposed techniques in mitigating interference at high data rates. The thesis is organized as follows:

Chapter 2: A brief description of impulse radio UWB based communication system is discussed. UWB communication system design including its transmission, reception, advantages, disadvantages and applications are presented. Comparison with other existing wireless standards and regulations are briefly described in this chapter. Pulse generation and shaping are the fundamental considerations in UWB system design. Three types of UWB pulses employed in the recent UWB research are Gaussian pulse, monocycle pulse, and doublet pulse. These pulses are usually referred to conduct basic theoretical analysis and simulation study. Further UWB channel models for WPAN indoor channel environments are analyzed in detail and their parameters are discussed.

Chapter 3: The Impulse Radio based Ultra Wideband (IR-UWB) system transmits data by sending pulses, each with very small time duration followed by pauses that are approximately two hundred times that length. Rake receiver improves system performance by equalizing signals from different paths. This enables the use of Rake receiver techniques in UWB systems. For high data rate ultra wideband communication system, performance comparison of ARake, PRake and SRake receivers are attempted.

The narrow band systems may cause interference with UWB devices as it is having very low transmission power and the large bandwidth. So it may jam the UWB receiver completely degrading their performance. Rake receiver alone fails to perform in such condition. A hybrid SRAKE-MMSE time domain equalizer is proposed to overcome this by taking the advantages of both the effect of the number of rake fingers and equalizer taps. This scheme selects the first strongest multipath components and combines them using a SRake receiver based on the minimum mean square error (MMSE) criterion. It also combats inter-symbol interference by considering the same advantages. Study on non-line of sight indoor channel models illustrates that bit error rate performance of UWB SRAKE-MMSE (both LE and DFE types) improves for CM3 model with smaller spread compared to CM4 channel model.

Chapter 4: TR-UWB system is a simple receiver structure which captures all of the energy available in a UWB multipath channel for demodulation at the receiver. TR is a correlation receiver system which does not require channel estimation and has weak dependence on distortion. The core part of TR-UWB scheme is known as auto correlation receiver (AcR) receiver. TR-UWB systems are susceptible to other interference because the interference will be multiplied at the receiver end. In this chapter, studies are performed and techniques are proposed for interference reduction in TR-UWB system. Two different strategies are suggested to improve the performance of the system-

- UWB Pulse Design using Eigen value decomposition technique
- Modified TR-UWB Receiver: Suppression of interference to the UWB system by incorporating a notch filter at the front end of UWB autocorrelation (AcR) receiver.

Suppression of interference from single NBI, multiple NBI and wideband interference to UWB system for different receivers are further provided using different channel models such as AWGN channel model and UWB channel models. The proposed technique does not reduce the capacity of the UWB system even the data rate changes from low to high data rate. Therefore it can be used for the better coexistence of other spectrally overlapping wireless systems with UWB system in the presence of ISI. MATLAB simulations are carried out for different channel conditions and BER performances are observed with and without ISI.

Chapter 5: This summarizes and concludes the research work in brief. Narrowband interference and Inter symbol Interference are major limitations of UWB system, which degrades the performance. Modified TR-UWB is found to be more efficient than other conventional like Rake receiver and Rake-MMSE, TR-UWB using AcR receiver in case of single NBI cancellation. Extensive simulation study show that proposed modified AcR receiver technique provides better performances in CM1, CM2 and CM3 channel model by suppressing single NBI, multiple NBI and WBI. The proposed eigen value decomposition method also provides some additional advantages such as the pulses meets FCC spectral mask, occupies a short duration and easy to implement to suppress the interference with ease. The modified TR-UWB receiver's efficacy is observed through BER performance improvement by mitigating interferers like NBI, multiple NBI and WBI and in high data rate eases.

Chapter 2

Overview of UWB Communication Systems

OVERVIEW OF UWB COMMUNICATION SYSTEMS

2.1 Introduction

Ultra Wideband wireless communication is emerging technology for transmitting large amounts of digital data over a wide frequency spectrum using short pulse, low powered radio signals [1], [4] and [58]. Impulse radio, a form of UWB spread spectrum signaling is used for short-range applications in dense multipath environments [2], [3]. An impulse radio concept is based upon transmitting and receiving very short pulses, which is carrier-less [8] and [9]. This chapter presents an overview of UWB communication system [14] and [72]. Pulse generation and pulse shaping are among the most fundamental problems in UWB systems [6], [17] and [18]. Accurate realistic wireless channel models are extremely important for analysis and efficient communication system design also [10], and [15]. The statistical characterization and modeling of the IEEE 802.15.3a wireless indoor channel models in details are analysed [19], simulated and discussed in this chapter.

Section 2.2 introduces the UWB technology defined by FCC. In section 2.3, UWB communication system is presented. Simulation results for UWB pulse design are presented in section 2.4. Section 2.5 explains IEEE 802.15.3a UWB channel model and section 2.6 investigates the simulation results of its statistical properties. The conclusion is presented in section 2.7.

2.2 UWB TECHNOLOGY

2.2.1 Definition

FCC has proposed a definition of UWB radio signals similar to that of Defense Advanced Research Projects Agency (DARPA) UWB radar panel [16] based on the fractional bandwidth, B_f of the signal.

The fractional bandwidth can be determined using formula

$$B_f = 2\frac{f_H - f_L}{f_H + f_L} \tag{2.1}$$

The fractional bandwidth (the ratio between signal bandwidth and centre frequency) is to be greater than 0.25 (25%) or the signal occupy at least 0.5 GHz of the spectrum [17]. The bandwidth is measured at the upper and lower cut off points (-10dB), f_H and f_L respectively [7]. The centre frequency f_C is defined as the average of these cut off points. This provided an efficient use of radio resource while enabling high data rate PAN wireless connectivity [18]. Fig. 2.1 provides the fractional bandwidth of UWB system.

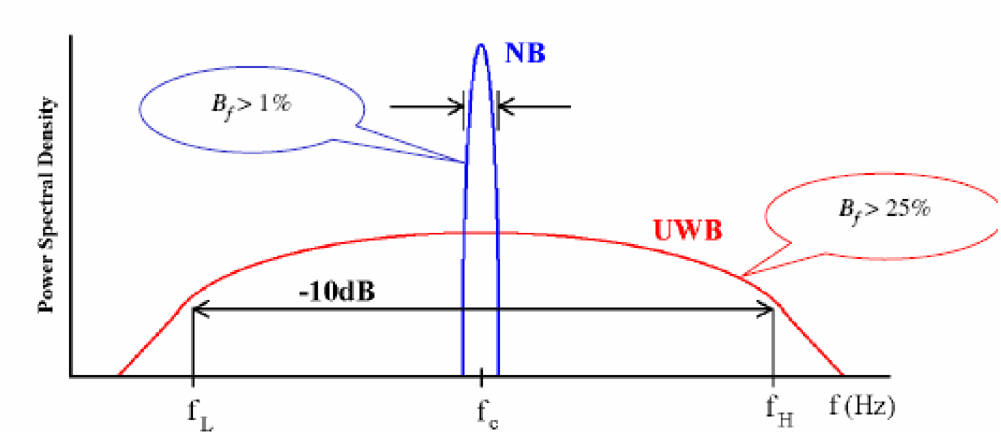


Fig. 2.1 Magnitude spectrum of narrowband and UWB system

2.2.2 UWB Regulation

In 1998, FCC recognized the importance of UWB technology and began the process of regulatory review. In February 2002, FCC made the formal rule that permits Ultra Wideband to operate under certain indoor and outdoor power spectral masks [16]. FCC has authorized unlicensed use in 3.1 - 10.6 GHz band for UWB signal and its power spectral density (PSD) to be less than -41.3 dBm/MHz, which is less than other wireless communication device.

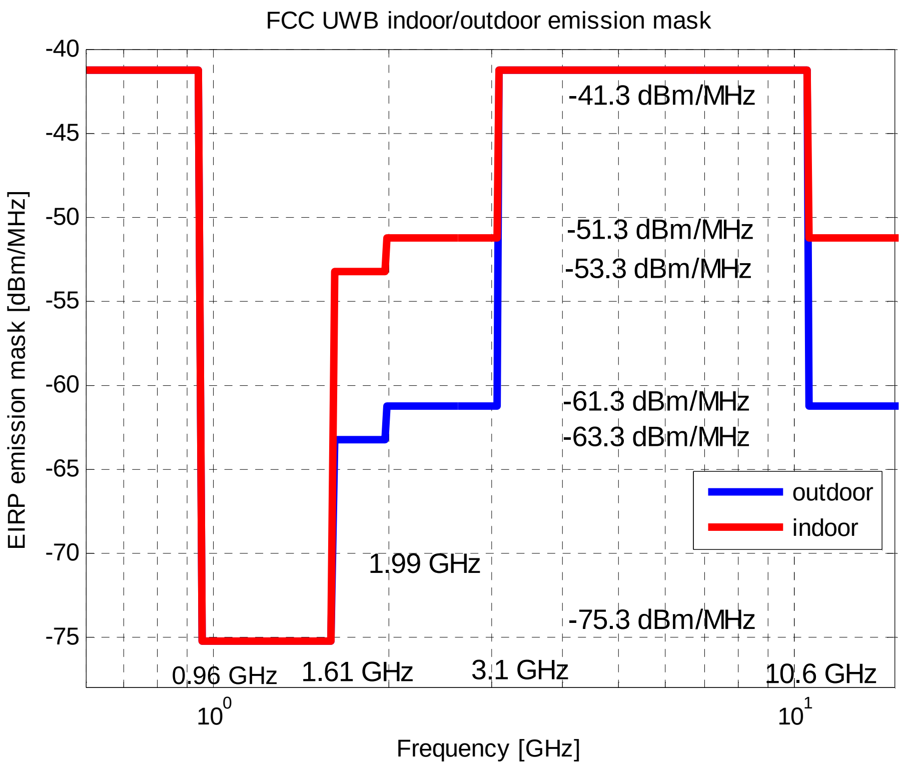


Fig. 2.2 FCC Emission mask for indoor and outdoor UWB systems

As shown in Fig. 2.2, for indoor applications, the emission power of UWB devices should be below -41.3 dBm/MHz from 0 Hz to 0.96 GHz, below -75.1 dBm/MHz from 0.96 GHz to 1.61 GHz, below -53 dBm/MHz from 1.61 GHz to 1.99 GHz, below -51.3 dBm/MHz from 1.99 GHz to 3.1 GHz, below -41.3 dBm/MHz from 3.1 GHz to 10.6 GHz, below -51.3 dBm/MHz from 10.6 GHz above. The emission power of UWB devices should be below -41.3 dBm/MHz from 0 Hz to 0.96 GHz, below -75.1 dBm/MHz from 0.96 GHz to 1.61 GHz, below -63.3 dBm/MHz from 1.61 GHz to 1.99 GHz, below -61.3 dBm/MHz from 1.99 GHz to 3.1 GHz, below -41.3 dBm/MHz from 3.1 GHz to 10.6 GHz, below -61.3 dBm/MHz from 10.6 GHz above for outdoor applications as shown in the same Fig. 2.1. The emission limits are defined as the effective isotropic radiated power (EIRP) in terms of milli-watt per 1 MHz bandwidth. For instance, the power spectral density of -41.3dBm/MHz is equivalent to the electric strength of 500 μV/m measured at a distance of 3 meters away from the radiator in a 1 MHz resolution bandwidth [16], [27] and [28].

2.2.3 ADVANTAGES & DISADVANTAGES OF UWB SYSTEM

UWB system has the following main advantages [27], [28], [32], [33], [58] and [72]

- According to Shannon's communication theory, UWB signals have the capability to convey high-speed data and the information capacity increases linearly with frequency bandwidth, and decreases logarithmically with the signal to noise ratio.
- In the wall penetrating radar, UWB signal can precisely track the moving objects behind the wall [5].
- UWB communication system is inherently secure.
- Impulse radio is carrier-less, so it only has base-band processing and no intermediate frequency (IF) processing is needed. This makes impulse radio devices much cheaper than other wireless communication devices [8].
- Battery life of UWB device will also be more because of the very low transmitted power as well as very low power consumption due to the more simple transceiver architecture of UWB devices.

Every technology has many challenges and difficulties. Some of the disadvantages of this promising technology includes: [27], [28], [32], [33], [58] and [72]

- Interference with existing narrow band turns out to be a critical problem as UWB signal uses a wide RF bandwidth. This interference could be in two directions, first one is the narrow band signals can interfere with UWB receivers, such as IEEE 802.11a that shares 5 GHz frequency band with UWB signals; the other one is that UWB signals may interfere into narrow band receivers [11], [13].
- Since UWB pulses are very short in time domain, high-speed Analog to Digital Converter and high-speed DSP are essential to digitize and process UWB signals. Sophisticated signal processing techniques are to be relied upon such carrier-less system [18].
- UWB systems require wide-band antennas. However, wide-band antennas are bigger and more expensive than narrow-band antennas, designing a small and inexpensive antenna is crucial for UWB technology to be widely deployed [14].

- UWB communication systems are limited in range. In order to make UWB interference to other radio systems insignificant, the transmission power of UWB signals has to be bounded under the emission mask set by the FCC [16].
- Since pulses with picoseconds precision are used in UWB, the time for a transmitter and receiver to achieve bit synchronization can be as high as a few milliseconds. So channel acquisition time is very high, which significantly affect the performance [15].

2.2.4 UWB APPLICATIONS

The various applications of UWB technology has include both commercial and military side on the basis of high data rate communication, short range applications, remotely sensing radar, vehicular radar and multimedia devices [27], [28], [32], [58] and [72].

- UWB communication systems are often advantageous in short-range WPANs using IEEE 802.15.3a standards [19] and [21]. UWB technologies are used in indoor applications of data rates in megabits per second, such as wireless USB, home entertainment, and high speed wireless LAN communications for voice, data and video application.
- UWB technique may be used to determine the range between two objects due to its precise time resolution using IEEE 802.15.4a task group [6] and [19]. UWB radar on the ship may sense the rail height relative to the water line, in the crude oil tank, UWB radar can measure the levels of oil, emulsion, and water layers at the same time.
- UWB radars may be used to detect and image the objects inside enclosed spaces or behind walls. UWB radar may determine or image the positions of people inside the rooms from outside. Through wall imaging is used for rescue, security and medical applications [2], [3] and [5].
- Vehicular radars use the frequency band surrounding 24 GHz to measure the location and movement of objects around a vehicle by transmitting UWB pulses and detecting the reflected signals [17] and [18]. These devices enable the features such as auto navigation, collision avoidance, improved airbag activation, intelligent suspension systems, etc.

- Military applications use UWB system for sensing enemy locations and tracking loops detection of land mines [5].
- Attaching UWB RFID task to each item inside a box, a scan to identify the item inside the box without opening it [72].

2.3 Ultra Wideband (UWB) Communication Systems

The UWB communication system is either pulse or multicarrier based communication [33] and [58]. In multicarrier based UWB system orthogonal frequency division multiplexing (OFDM) technique is employed to transmit information using orthogonal carriers [27], [28] and [32]. This requires sophisticated signal processing techniques and transceiver architecture [72]. In this research work single band or carrier less UWB system is focused [8]. A single link UWB communication system consists of three major blocks of communication, i.e. a source (transmitter), the channel, and destination (a receiver). The main function of the transmitter is to send the input data through the channel, to the destination with the help of antenna. Fig. 2.3 illustrates a generalized UWB transmitter model, which consists of UWB pulse generator, data modulation, filter and antenna [72].

UWB communication technique is fundamentally different from traditional radio transmission as it is carrier less, meaning that data is not modulated on a continuous waveform with a specific carrier frequency [10] and [14]. It employs extremely narrow radio frequency pulses generated from UWB pulse generator to communicate between transmitter and receiver. From Fourier analysis, it is understood a very short that signal in time domain produces a very wide spectrum signal in frequency domain and hence utilizing short duration pulses generates a very wide bandwidth [32] and [33]. Hence UWB transmission can transmit information by generating radio energy at specific time instants and occupying large bandwidth thus enabling a pulse position or time modulation.

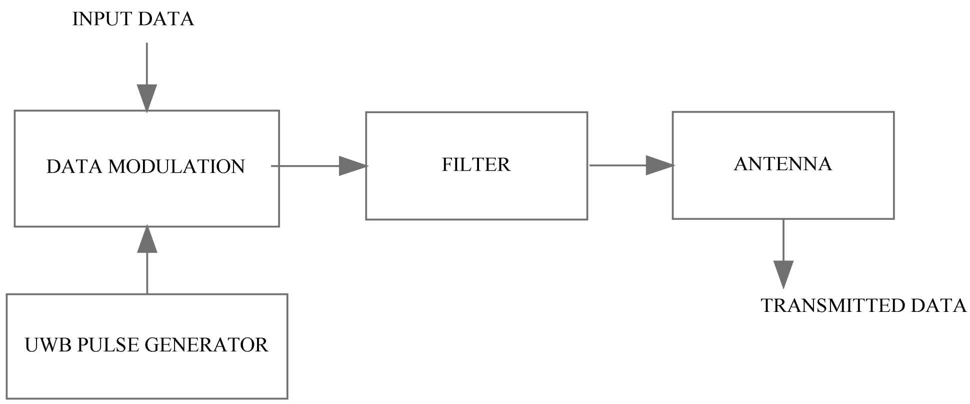


Fig. 2.3 General Model of UWB transmitter

Information can be modulated on UWB pulses by encoding the polarity of the pulse, the amplitude of the pulse and/or by using orthogonal pulses. The transmission of low-powered pulses eliminates the need for a power amplifier in UWB transmitter. Also there is no need for mixers and local oscillators to translate carrier frequency and also carrier recovery at receiver’s frequency band. So pulse based UWB system is significantly simpler to design and cheaper to build. The UWB receiver model to extract the desired information from the received signal is shown in Fig. 2.4. The frontend filter filters out the noisy components of the received signal. Low noise amplifier amplifies the signal it continuous on into the receiver end [72].

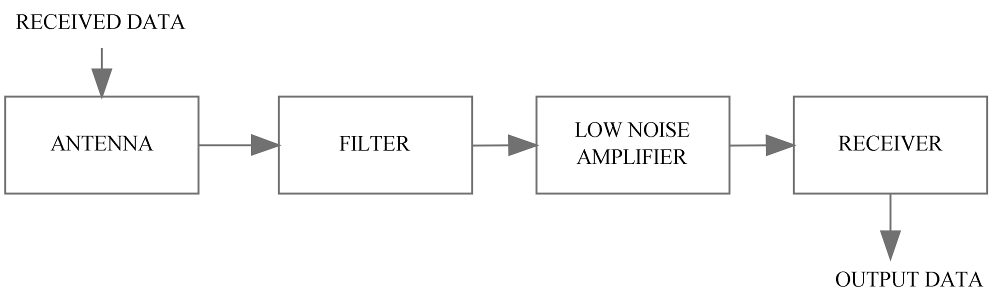


Fig. 2.4 General Model of UWB receiver

2.4 UWB PULSE DESIGN

UWB is known to be the transmission of ultra short duration pulses, with bandwidths in the gigahertz range according to FCC ruling [16]. Such pulses provide spreading of energy over a large bandwidth because of the sharp rise and fall of the pulse. In addition, the power spectral density is so low for any given frequency that it provides the possibility of low probability of detection or intercept communications. The short pulses also offer immunity to multipath fading and a much lower fading margin, which gives multipath resolution. There are three types of UWB pulses usually referred as Gaussian pulse, Gaussian monocycle (Gaussian pulse of first derivative), and Gaussian doublet (Gaussian pulse of second derivative) [17] and [18].

2.4.1 Gaussian pulse:

The Gaussian pulse for UWB communication system is defined as

$$p(t) = A\exp\left(-\frac{(t-t_0)^2}{2\tau^2}\right) \tag{2.2}$$

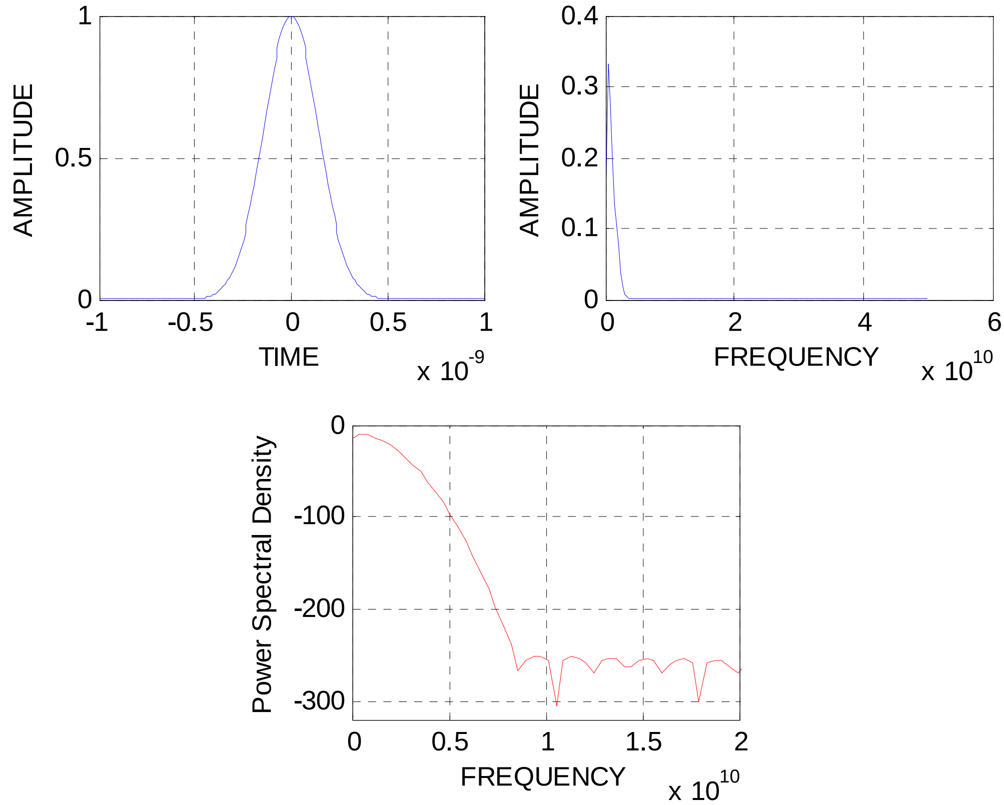


Fig. 2.5 Gaussian Pulse in time, frequency domain and Magnitude Spectrum

where A and t_0 provides the amplitude and time offset respectively and τ is the time constant gives the width of the pulse in seconds. Fig. 2.5 illustrates a Gaussian pulse having unity magnitude and pulse width of 1 ns and $t_0 = 0$. The -10 dB bandwidth of this signal is approximately 2 GHz.

2.4.2 Gaussian monocycle:

The Gaussian monocycle is the first derivative of Gaussian pulse [18], which is defined as

$$\frac{d}{dt} p(t) = A \frac{t}{\tau^2} \exp(-\frac{1}{2}((t - t_0)/\tau)^2) \tag{2.3}$$

Fig. 2.6 shows a Gaussian monocycle pulse having unity magnitude and pulse width of 1 ns and $t_0 = 0$. The -10 dB bandwidth of this signal is approximately 2.5 GHz.

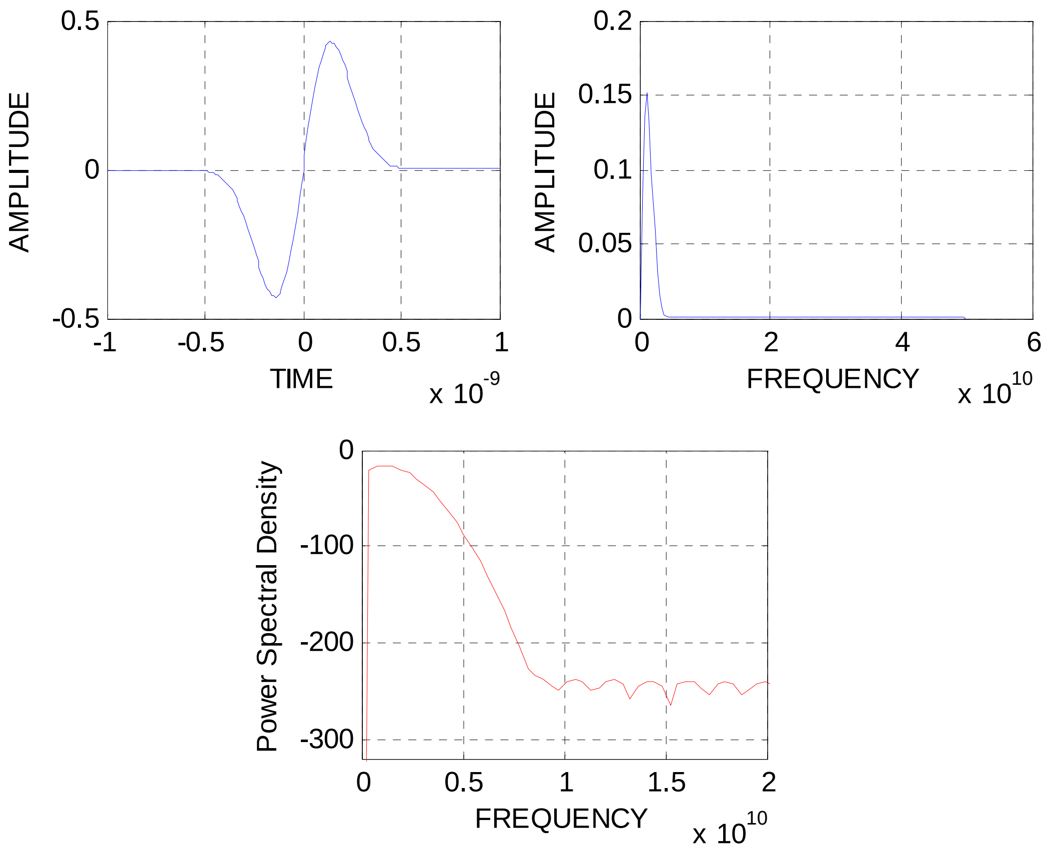


Fig. 2.6 Gaussian monocycle in time, frequency domain and Magnitude Spectrum

2.4.3 Gaussian doublet

Gaussian doublet is the second derivative of Gaussian pulse and is mathematically given as

$$\frac{d^2}{dt^2}p(t) = A\left[\frac{1}{\tau^2}\exp(-\frac{1}{2}((t-t_0)/\tau)^2) - \frac{t^2}{\tau^4}\exp(-\frac{1}{2}((t-t_0)/\tau)^2)\right] \quad (2.4)$$

Fig. 2.7 gives a Gaussian doublet pulse having unity magnitude and pulse width of 1ns and $t_0 = 0$. The -10dB bandwidth of this signal is approximately 2.7 GHz. Comparing the power density spectrum for the given pulse shapes it is observed that centers of monocycle and doublet are skewed to higher frequency and further doublet is more skewed compared to a monocycle.

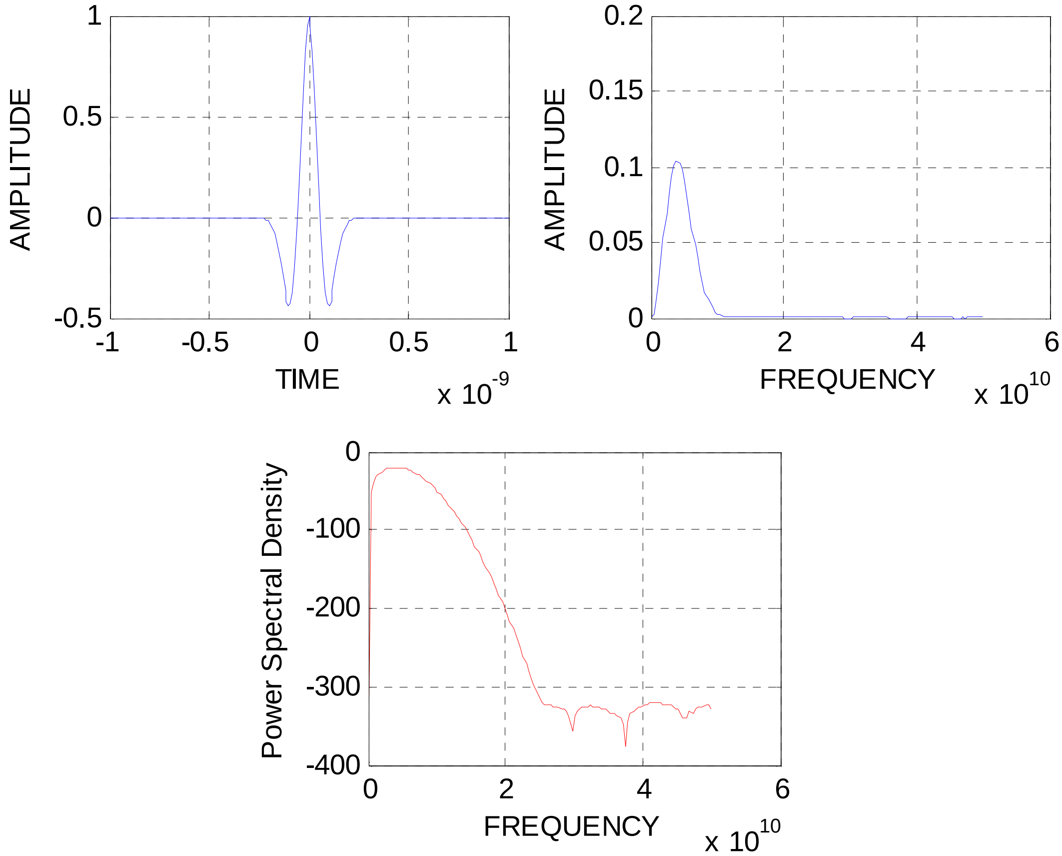


Fig. 2.7 Gaussian doublet in time, frequency domain and Magnitude Spectrum

2.5 UWB CHANNEL MODEL

The accurate design of channel model is a significant issue for ultra wideband WPAN communication system. Such a model creates the facility for calculation of large and small-scale statistics [7] and [15]. Specifically large-scale models are necessary for network planning and link budget design and small-scale models are necessary for efficient receiver design. The most famous multipath UWB indoor channel models are tap-delay line Rayleigh fading model, Saleh and Valenzuela (S–V) model and Δ-K model. The S–V channel measurement shows that the multipath components are arriving in a cluster form [52]. The different paths of such wide band signal can rise to several multipath components, all of which will be part of one cluster. The arrival of multipath components is modeled by using Poisson distribution and thus the inter arrival time between multipath components is based on exponential distribution. The multipath arrival of UWB signals are grouped into two categories: cluster arrival and ray arrival within a cluster. This model requires several parameters to describe indoor channel environments [53]. Ray arrival rate is the arrival rate of path within each cluster. The cluster arrival rate is always smaller than the ray arrival rate. The amplitude statistics in S–V model are based on lognormal distribution, the power of which is controlled by the cluster and ray decay factor [20] and [21]. Indoor channel environments are classified as CM1, CM2, CM3, and CM4 following IEEE 802.15.3a standard based on propagation conditions as follows [19].

- CM1 describes a line-of sight (LOS) scenario with a maximum distance between transmitter and receiver of less than 4m.

- CM2 describes the same range as of CM1, but for a non-line-of sight (NLOS) situation.

- CM3 describes a NLOS medium for separation between transmitter and receiver of range 4-10m.

- CM4 describes an environment of more than 10m with strong delay dispersion, resulting in a delay spread of 25ns with NLOS medium.

Table 2.1 UWB channel characteristics

Channel Characteristics	CM 1 LOS(0-4m)	CM 2 NLOS(0-4m)	CM 3 LOS(4-10m)	CM 4 LOS(>10m)
Cluster arrival rate {Λ} (1/nsec)	0.0233	0.4	0.0667	0.0667
Ray arrival rate {λ} (1/nsec)	2.5	0.5	2.1	2.1
Cluster decay factor {Γ} (1/nsec)	7.1	5.5	14.00	24.00
Ray decay factor {γ} (1/nsec)	4.3	6.7	7.9	12
Standard deviation of cluster lognormal fading term σ_1 (dB)	3.3941	3.3941	3.3941	3.3941
Standard deviation of ray lognormal fading term σ_2 (dB)	3.3941	3.3941	3.3941	3.3941
standard deviation of lognormal shadowing term σ_x (dB)	3	3	3	3

Table 2.1 describes the UWB channel characteristic in detail in case of multipath environment. We have employed the model proposed by the IEEE 802.15.3a channel modeling group [19] based on modification of the Saleh and Valenzuela [52]. This model takes into account the clustering phenomenon observed in several UWB channel measurements [54] and [62].

According to [19] and [70], the channel impulse response is

$$h(t) = X\sum_{l=0}^{L-1}\sum_{k=0}^{K-1}\alpha_{k,l}\delta(t-T_l - \tau_{k,l}) \tag{2.5}$$

where $\{\alpha_{k,l}\}$ are the multipath gain coefficient of k^{th} ray related to l^{th} cluster, $\{T_l\}$ is the delay or arrival time of first path of the l^{th} cluster, $\{\tau_{k,l}\}$ is the delay of the k^{th} multipath component within the l^{th} cluster relative to arrival time $\{T_l\},\{X\}$ represents the log-normal shadowing term.

Equation 2.6 provides the cluster arrival time and the ray arrival distribution time

$$p\left(T_l \middle| T_{l-1}\right) = \Lambda \exp\left[-\Lambda\left(T_l - T_{l-1}\right)\right], \quad l > 0$$
$$p\left(\tau_{k,l} \middle| \tau_{(k-1),l}\right) = \lambda \exp\left[-\lambda\left(\tau_{k,l} - \tau_{(k-1),l}\right)\right], \quad k > 0 \tag{2.6}$$

We have $\tau_{0,l} = 0$. If the channel coefficients are considered as real, then $p_{k,l}$ takes real random value +1 or −1.

The channel coefficients are defined as:

$$\alpha_{k,l} = p_{k,l}\xi_l\beta_{k,l} \tag{2.7}$$

If complex base band channel is considered, the channel co-efficient phase is uniformly distributed over the interval [0, 2π]. $\beta_{k,l}$ is the amplitude of the UWB signal. It is based on lognormal distribution and is given as

$$20\log 10(\xi_l\beta_{k,l}) \propto Normal(\mu_{k,l}, \sigma_1^2 + \sigma_2^2) \tag{2.8}$$

or

$$\left|\xi_l\beta_{k,l}\right| = 10^{(\mu_{k,l}+n_1+n_2)/20} \tag{2.9}$$

where σ_1 is the standard deviation of cluster lognormal fading term. σ_2 is the standard deviation of ray lognormal fading term and $n_1 \propto Normal(0,\sigma_1^2)$ and $n_2 \propto Normal(0,\sigma_2^2)$ are independent and correspond to the fading on each cluster and ray, respectively,

The behavior of the averaged power delay profile is

$$E\left[\left|\xi_l\beta_{k,l}\right|^2\right] = \Omega_0 e^{-T_l/\Gamma} e^{-\tau_{k,l}/\gamma} \tag{2.10}$$

where Ω_0 is the mean energy of the first path of the first cluster.

The $\mu_{k,l}$ is given by

$$\mu_{k,l} = \frac{10\ln(\Omega_0) - 10T_l/\Gamma - 10\tau_{k,l}/\gamma}{\ln(10)} - \frac{(\sigma_1^2 + \sigma_2^2)\ln(10)}{20} \tag{2.11}$$

Where, ξ_l reflects the fading associated with the lth cluster, and $\beta_{k,l}$ corresponds to the fading associated with the k^{th} ray of the l^{th} cluster. This reflects the exponential decay of each ray as well as decay of the total cluster power with respect to delay. X is the shadowing term and it is characterized by following

$$20\log 10(X) \propto Normal(0, \sigma^2) \tag{2.12}$$

σ is the standard deviation of lognormal shadowing term.

2.6 SIMULATION RESULTS OF UWB CHANNEL STATISTICAL PROPERTIES

The main characteristics of the channel that are used to derive the above model parameters are as follows: Mean excess delay, RMS delay spread, number of multipath arrivals that are within 10 dB of the peak multipath arrival, average power delay profile [70]. Extensive simulation results under various channel conditions are presented in this section.

Table 2.2 Statistics of UWB channel realization

Target Statistical properties	CM 1	CM 2	CM 3	CM 4
Mean excess delay (nsec) (τ_m)	5.05	10.38	14.18	-
RMS delay (nsec) (τ_{rms})	5.28	8.03	14.28	25
NP10dB	-	-	35	-
NP (85%)	24	36.1	61.54	-
Model Statistical properties				
Mean excess delay (nsec) (τ_m)	5.0	9.9	15.9	30.1
RMS delay (nsec) (τ_{rms})	5	8	15	25
NP10dB	12.5	15.3	24.9	41.2
NP (85%)	20.8	33.9	64.7	123.3
Channel energy mean (dB)	-0.4	-0.5	0.0	0.3
Channel energy std (dB)	2.9	3.1	3.1	2.7

Table 2.2 provides both target and model statistics of UWB channel model [19]. The simulated channel impulse responses, the average power delay profiles and other statistical characteristics for CM1, CM2, CM3 and CM4 are shown in Fig. 2.8, Fig. 2.10, Fig. 2.12 and Fig. 2.14. The channel energy for CM1, CM2, CM3 and CM4 are plotted in Fig. 2.9, Fig. 2.11, Fig. 2.13 and Fig. 2.15 respectively.

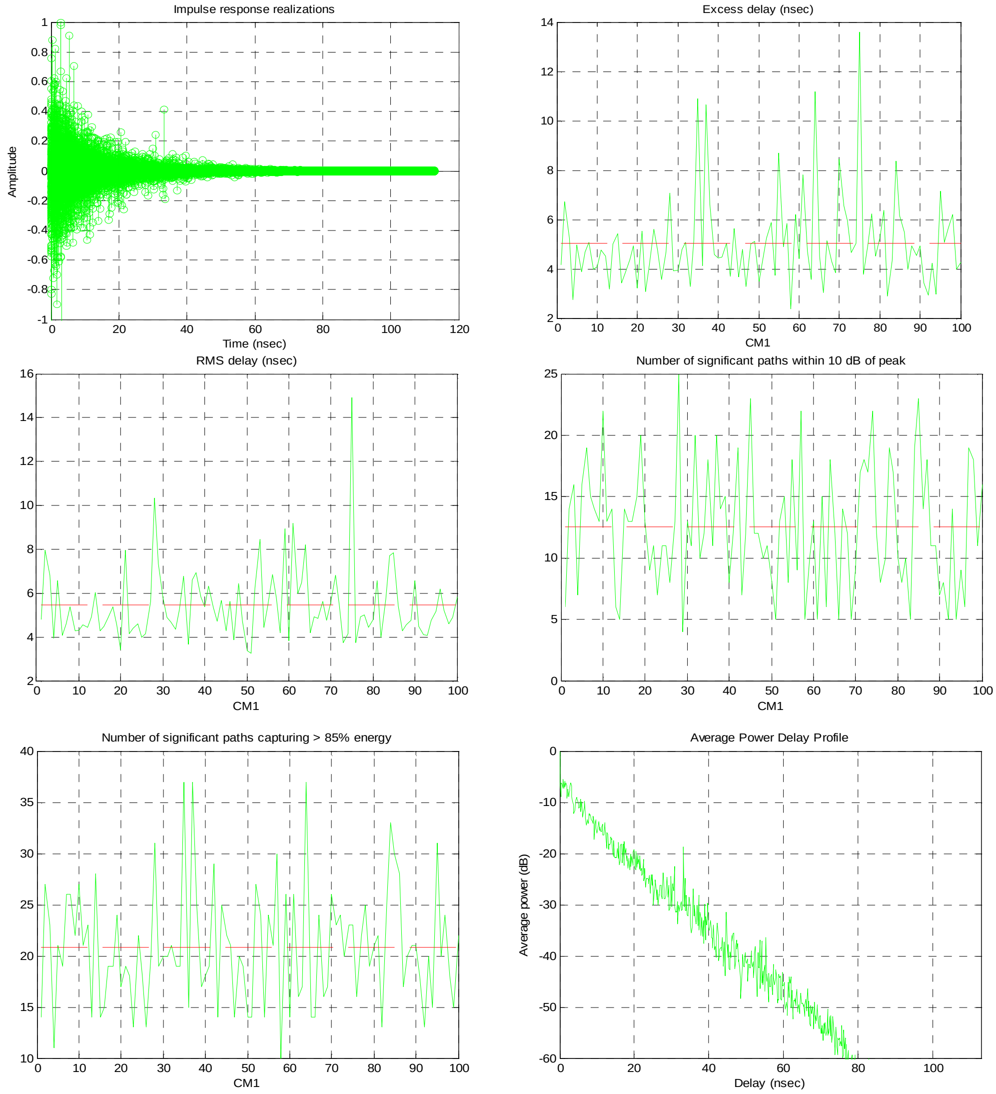


Fig. 2.8 Realization of CM1 channel model parameters

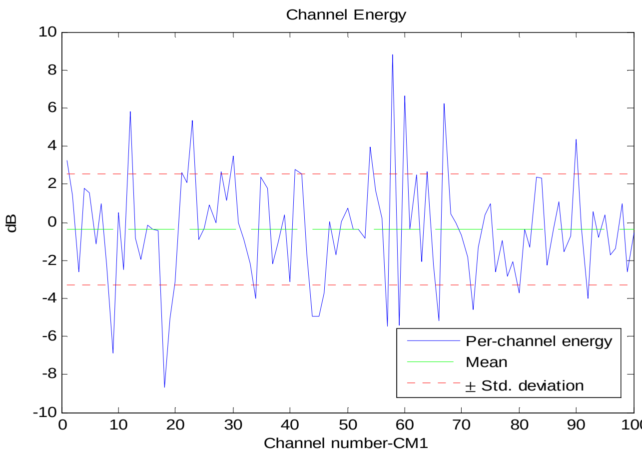


Fig. 2.9 Channel energy of CM1 channel model

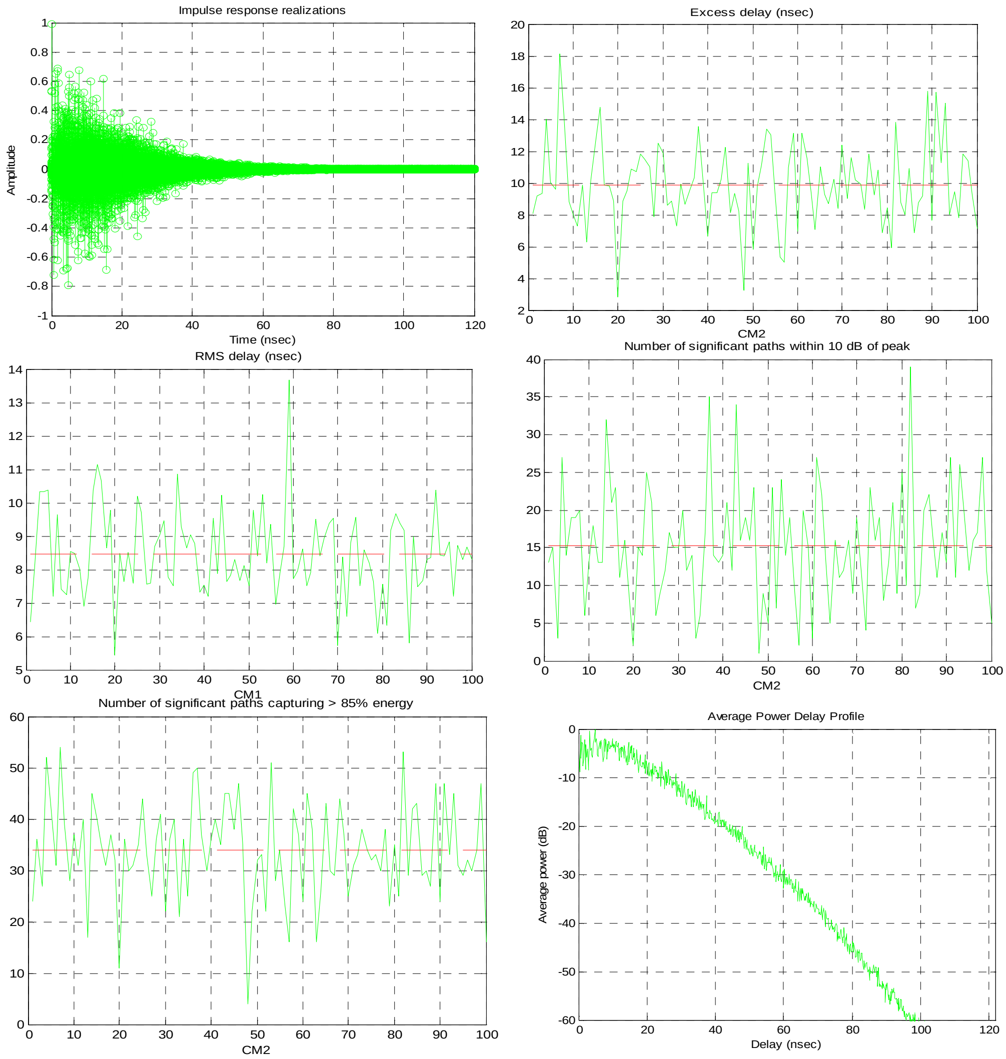


Fig. 2.10 Realization of CM2 channel model parameters

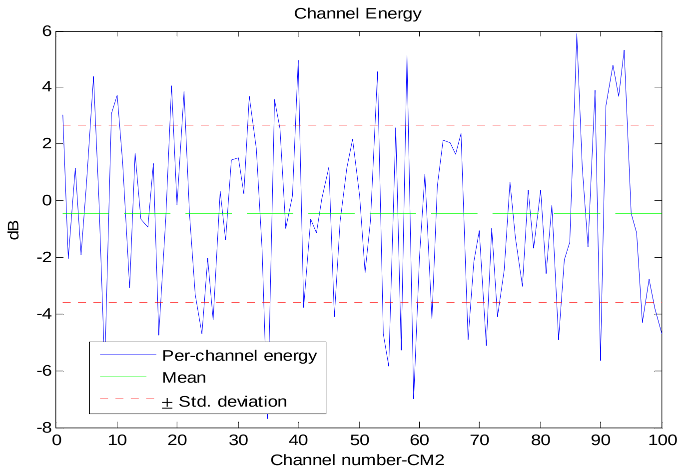


Fig. 2.11 Channel energy of CM2 channel model

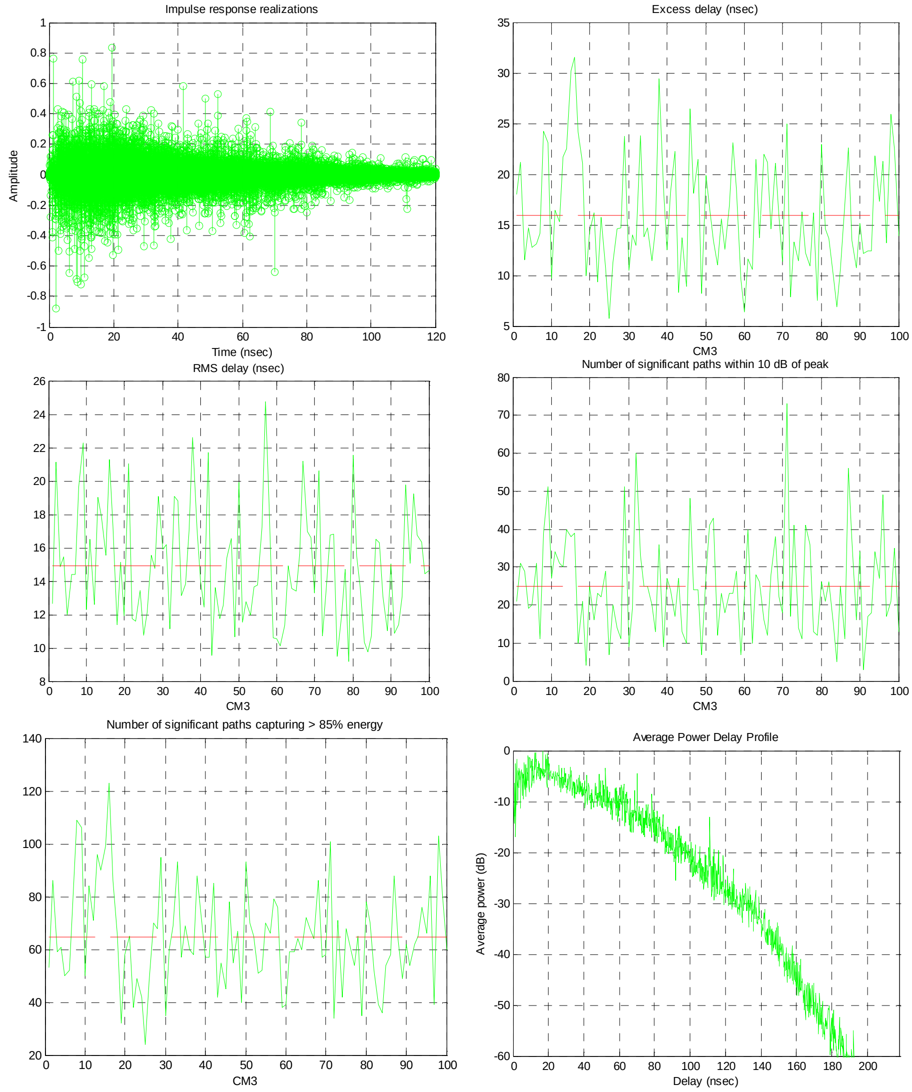


Fig. 2.12 Realization of CM3 channel model parameters

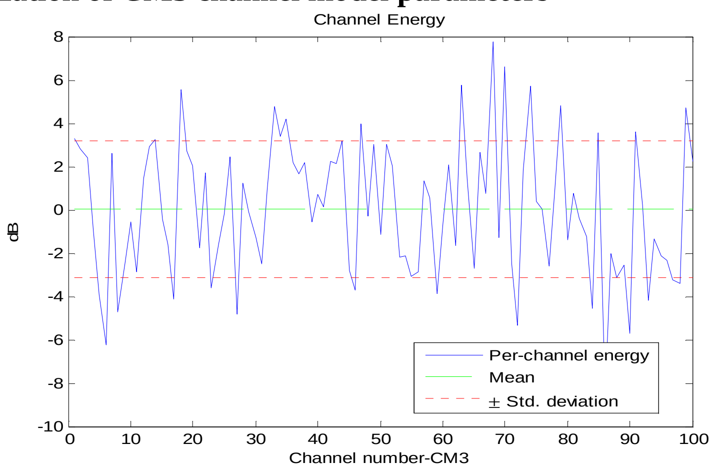


Fig. 2.13 Channel energy of CM3 channel model

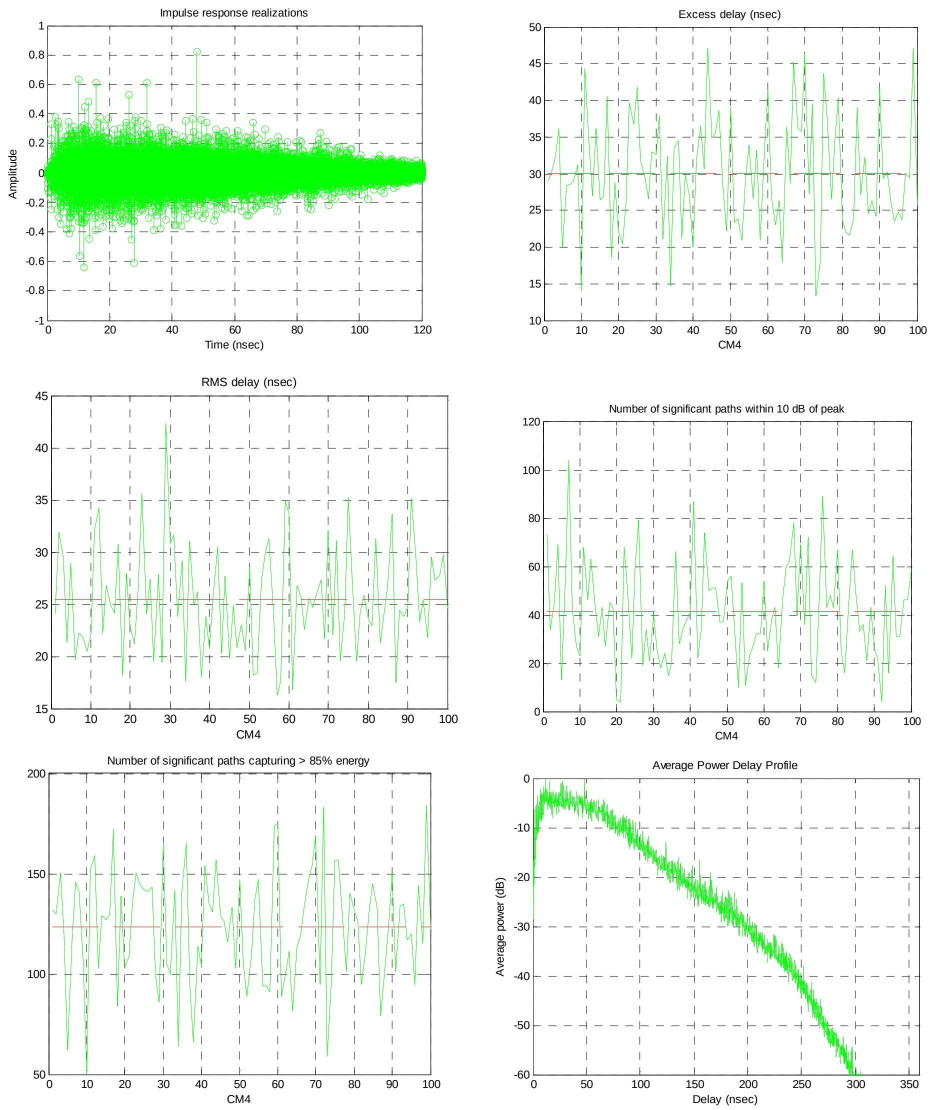


Fig. 2.14 Realization of CM4 channel model parameters

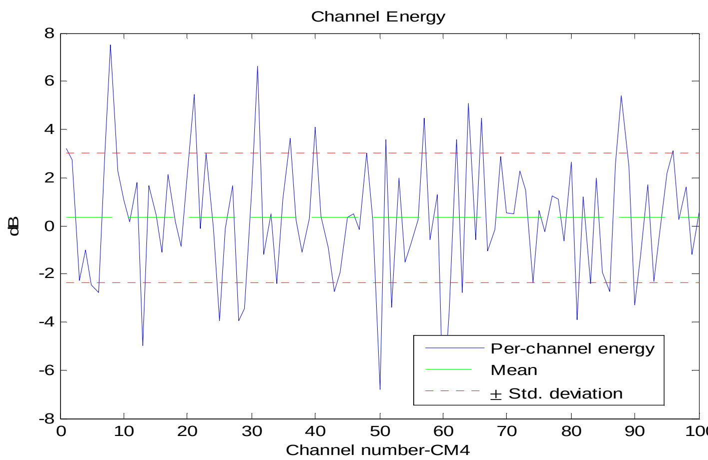


Fig. 2.15 Channel energy of CM4 channel model

2.7 Conclusion

In this chapter, the basic concepts of UWB technique are discussed. It is concluded that UWB technique has the potential of enhancing the data rate in WPANs. A brief description of the UWB communication system is given in this chapter. Advantages, disadvantages and prominent applications of UWB are briefed. Various Gaussian UWB pulse shapes referred in theoretical and simulation study are implemented. Four types of wireless indoor UWB channel models for WPAN indoor channel environments based on IEEE 802.15.3a standard are analyzed in detail and their parameters are discussed. Channel Impulse response, Power Delay Profile, Mean excess delay, RMS delay spread, Channel energy mean, standard deviation etc. are investigated through simulation.

Chapter 3

Narrowband Interference reduction in Impulse Radio (IR) UWB Communication systems

NARROWBAND INTERFERENCE REDUCTION IN IMPULSE RADIO (IR) UWB COMMUNICATION SYSTEMS

3.1 Introduction

A traditional UWB technology is based on single band systems employing carrier free or impulse radio communications. Impulse radio (IR) refers to the generation of a series of impulse like waveforms, each of duration in the hundreds of picoseconds [8], [9] and [22]. This type of transmission does not require the use of additional carrier modulation and is a baseband signal approach. UWB technology provides high data rate with low power spectral density due to modulation of extremely short pulses within 3.1 to 10.6 GHz [16]. The very low transmission power and the large bandwidth enable an UWB system to co-exist with narrowband communication [11] systems illustrated in Fig. 3.1. Although UWB communication offers a promising solution in an increasingly overcrowded frequency spectrum, mutual interference due to coexistence with other spectrally overlapping wireless system degrades the performance of both systems [13]. The interference caused may jam the UWB receiver completely. According to Electromagnetic Compatibility (EMC) reports submitted to FCC [72], the narrowband interferences (NBI) expected by the UWB receivers are computer motherboard of emission level 42.7dBm at 1.9 GHz, IEEE 802.11b at centre frequency 2.4 GHz, network interface card (NIC) of emission level 49.8dBm at 3.75 GHz, LAN switch of 44.3dBm at 3.75 GHz, peripheral component interconnect (PCI) card for a personal computer 3.75 GHz and IEEE 802.11a (WLAN system) at centre frequency 5.25 GHz etc. [11]. Study of impact of NBI and suppression of NBI is one of the important issues associated with UWB applications [36], [37] and [38] and [57]. Performance enhancement by employing effective NBI mitigation techniques are discussed in this chapter.

Section 3.2 introduces the principle of UWB Rake receiver considering its importance in UWB system. In section 3.3, UWB Rake receiver structure is analyzed in the presence of NBI. Simulation results for performance analysis of UWB Rake receiver and performance degradation of UWB SRake receiver in presence of NBI are presented in section 3.4 and 3.5 respectively. Section 3.6 explains the performance of UWB SRAKE-MMSE receiver and section 3.7 investigates the suppression of interference by using those receivers. Simulation results are presented in section 3.8. The conclusion is presented in section 3.9.

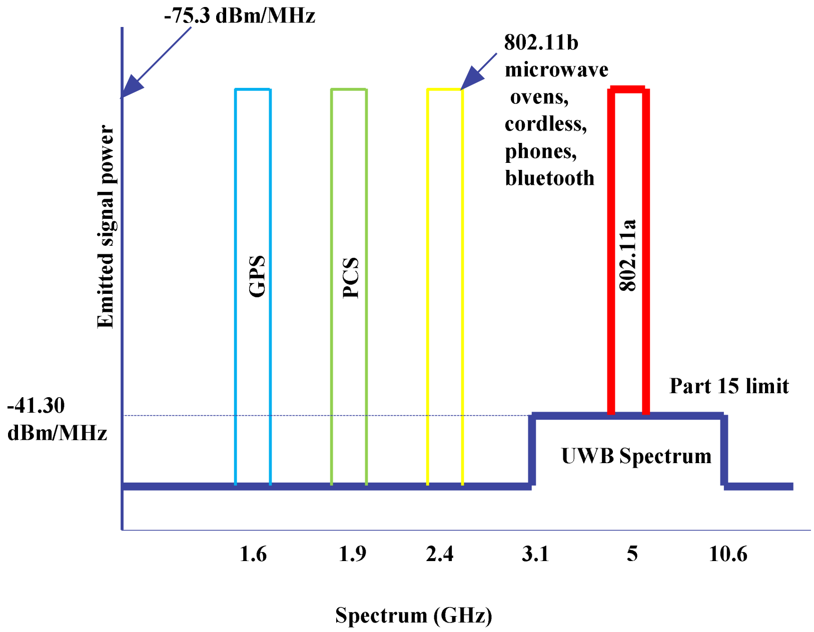


Fig. 3.1 Spectrum of UWB and existing narrowband systems

3.2 UWB RAKE RECEIVER STRUCTURE

The robustness of UWB signals to multipath fading [11] is due to their fine delay resolution, which leads to a high diversity order once combined with a Rake receiver. Rake receivers are used in time-hopping impulse radio systems and direct sequence spread spectrum systems for matched filtering of the received signal [9], [55] and [56]. The receiver structure consists of a matched filter that is matched to the transmitted waveform that represents one symbol and a tapped delay line that matches the channel impulse response [24] and [26]. It is also possible to implement this structure as a number of correlators that are sampled at the delays related to specific number of multipath components; each of those correlators is known as rake finger. Based upon the Rake receivers are three types. The All-Rake (ARake) receiver captures all most all the energy carried by a very large number of different multipath signals [23] and [25]. To reduce the rake complexity, a partial combining (called PRake) is used as partial combining of the energy, which combines the first arriving paths out of the available resolved multipath components. Selective combining (called SRake) is a suboptimum Rake receiver, which combines the energy selectively carried out by the strongest multipath components. A UWB Rake receiver structure is shown in Fig. 3.2.

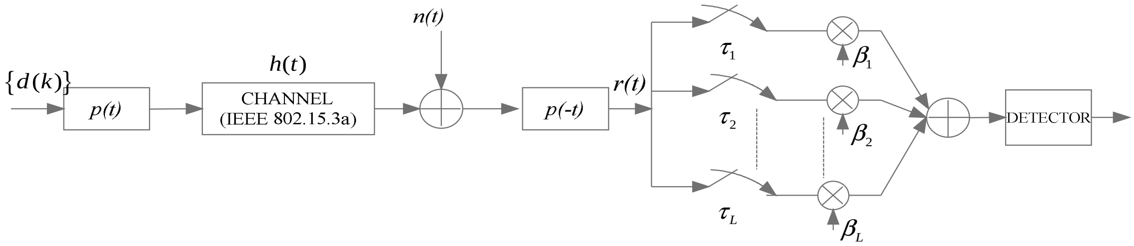


Fig. 3.2 UWB Rake receiver structure

For a single user system, the continuous transmitted data stream is represented as [25]

$$s(t) = \sum_{k=-\infty}^{+\infty} d(k)\, p(t - k.T_s) \tag{3.1}$$

where *d(k)* are stationary uncorrelated BPSK data and T_s is the symbol duration. The UWB pulse *p(t)* has duration T_{uwb} ($T_{uwb} < T_s$).

The channel impulse response is given by [70]

$$h(t) = \sum_{i=0}^{M} h_i \delta(t - \tau_i) \tag{3.2}$$

M is the total number of paths in the channel.

The received signal first passes through the receiver filter matched to the transmitted pulse and is given by

$$\begin{aligned} r(t) &= s(t) * h(t) * p(-t) + n(t) * p(-t) \\ &= \sum_{k=-\infty}^{+\infty} d(k) \sum_i h_i . m(t - k.T_s - \tau_i) + \hat{n}(t) \end{aligned} \tag{3.3}$$

where $p(-t)$ represents the receiver matched filter and $n(t)$ is the Additive White Gaussian Noise (AWGN) with zero mean and variance $N_0/2$. Also, $m(t) = p(t) * p(-t)$ and $\hat{n}(t) = n(t) * p(-t)$.

Combining the channel response with the transmitter pulse shape and the matched filter,

$$\tilde{h}(t) = p(t) * h(t) * p(-t) = \sum_{i=0}^{M} h_i m(t - \tau_i) \tag{3.4}$$

The received signal sampled at the l^{th} rake finger in the n^{th} data symbol interval is given by

$$v\left(n.T_s + \tau_l^{'} + t_0\right) = \sum_{k=-\infty}^{+\infty} \tilde{h}\left(\left(n-k\right).T_s + \tau_l^{'} + t_0\right).d\left(k\right) \tag{3.5}$$

where $\tau_l^{'}$ is the delay time corresponding to the l^{th} rake finger and is an integer multiple of T_m. Parameter t_0 corresponds to a time offset and is used to obtain the best sampling time. For the following analysis t_0 will be set to zero.

The Rake combiner output at time $t = n.T_s$ is

$$y[n] = \sum_{l=1}^{L} \beta_l v\left(n.T_s + \tau_l^{'}\right) + \sum_{l=1}^{L} \beta_l \hat{n}\left(n.T_s + \tau_l^{'}\right) \tag{3.6}$$

3.3 UWB SRAKE RECEIVER IN PRESENCE OF NBI

The working of UWB system in co-existence with other narrowband systems over their large bandwidth is challenging [57]. Thus, UWB systems must cope with these narrow band interference (NBI) using their high processing gain. However, due to very low transmission power, it is not sufficient to suppress high levels of NBI, which are typically from nearby narrowband radio systems having a bandwidth up to a few MHz. In many cases, the power of NBI is a few tens of dBs higher than both the signal and noise power. The narrowband interference (NBI) signal is modeled as a traditional single carrier BPSK modulated waveform, given by [26] and [36]

$$i\left(t\right) = \sqrt{2P_l}\cos\left(\omega_0 t + \theta\right) \sum_{p=-\infty}^{\infty} g_k z(t - kT_1 - \tau_1) \tag{3.7}$$

where, P_l is average transmit power of the narrowband waveform. $\omega_0 = 2\pi f_0$ is carrier frequency of the narrowband waveform. θ is the random phase of the carrier.

$\{g_k\}$ are the randomly modulated BPSK symbols where $g_k \in \{\pm 1\}$, T_1 is the symbol period, τ_1 is a random delay uniformly distributed in *[0, T_1]* and *z(t)* is the baseband wave form shape. UWB Rake receiver model considering NBI is shown in Fig. 3.3.

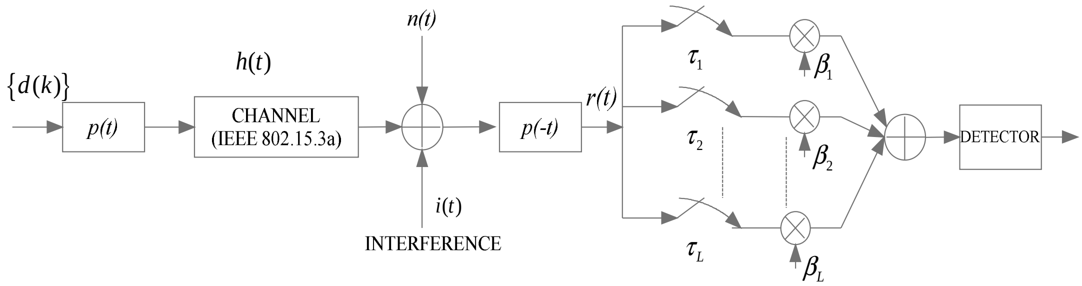


Fig. 3.3 UWB Rake receiver model in presence of NBI

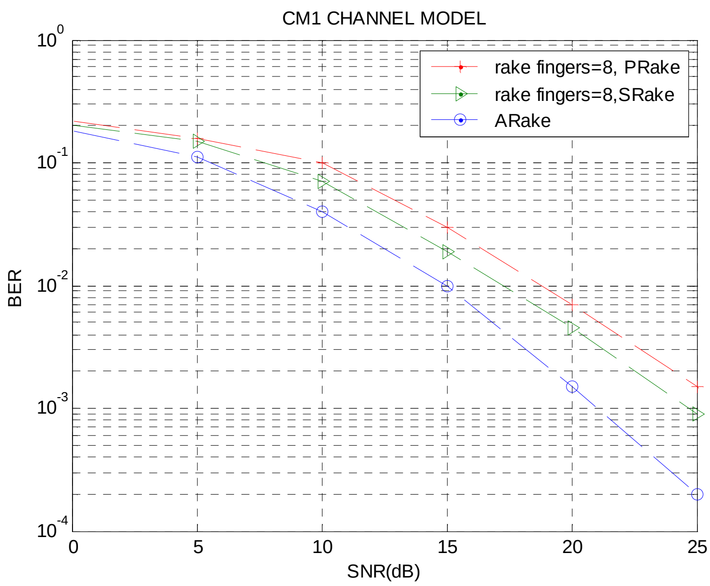
The received signal passes through the receiver filter matched is given by [26]

$$r(t) = A(t) * h(t) * p(-t) + n(t) * p(-t) + i(t) * p(-t) \tag{3.8}$$

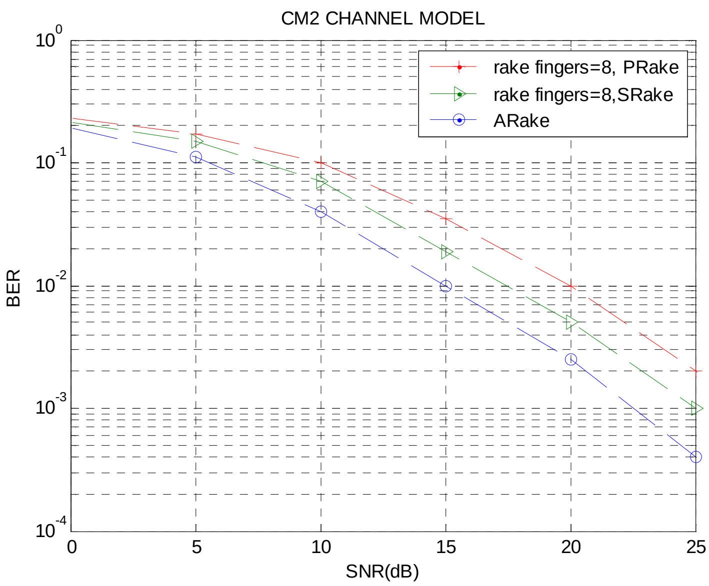
Interference coexisting with the same system generates extra signal which can't be easily detected at the output. Rather by coexisting with original pulse, it will decrease the performance of receiver. If such an interference is not properly suppressed, then this will jam the receiver and the system performance degrades [57].

3.4 PERFORMANCE ANALYSIS OF RAKE RECEIVERS IN IR-UWB SYSTEM

BER performance of Rake receiver in IR-UWB system is observed through MATLAB simulation. Performance comparison among ARake, SRake, and PRake receiver is carried out using different IEEE UWB channel models as shown in Fig. 3.4. ARake receiver provides better result than other two types of Rake. Since a UWB signal has a very wide bandwidth, ARake receiver combining all the paths of the incoming signal is practically unfeasible. Therefore, SRake becomes the practical choice. It is observed form Fig. 3.4 (a) that using the perfect channel impulse response and estimating 8 number of rake fingers; ARake provides best performance of gaining more than 4dB SNR over the PRake receiver at BER=10^{-3}. It is also found that SRake and PRake have almost the same diversity order, and differs by less than 2dB due to line of sight (LOS) channel medium.



(a)



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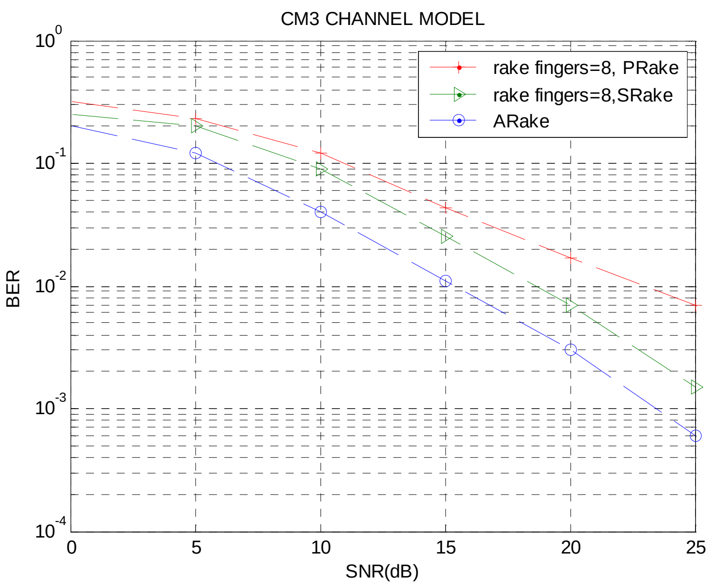
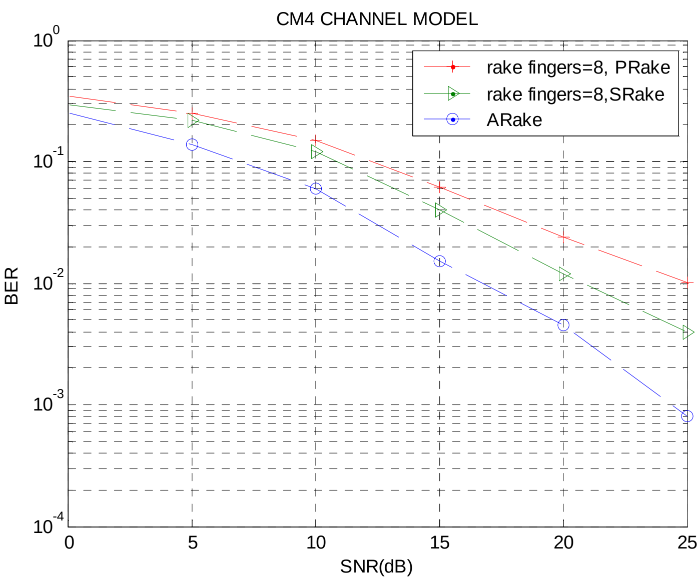


(c)



(d)

Fig. 3.4 BER performance of Rake receivers for IEEE UWB channel models

In the analysis CM2 channel model, SRake performance approaches almost the same performance level as ARake. SRake receiver provides 3dB SNR improvement at 10^{-2} BER floor over the PRake as shown in Fig. 3.4 (b). In Fig. 3.4 (c) showing SRake receiver performance, gain of more than 4dB SNR over the PRake at BER=10^{-2} for

NLOS CM3 channel environment. Using CM4 channel model, for the same simulation parameter SRake performs better as shown in Fig. 3.4 (d). A SNR gain of more than 5dB is observed on 10^{-2} BER floor for SRake. At low SNR's the system noise is more and hence the system degradation is noticed. More signal energy capture is required to overcome it. This can be achieved by increasing the numbers of rake fingers in Rake receiver structure.

3.5 STUDY OF PERFORMANCE DEGRADATION OF UWB SYSTEM IN PRESENCE OF NBI

SRake receiver in UWB system performance in absence and presence of NBI is studied and found that NBI deteriorates the system performance. In this study SRake with both 3 and 5 rake fingers is considered. An NBI with signal to interference ratio (SIR) of -20dB is added to the channel model.

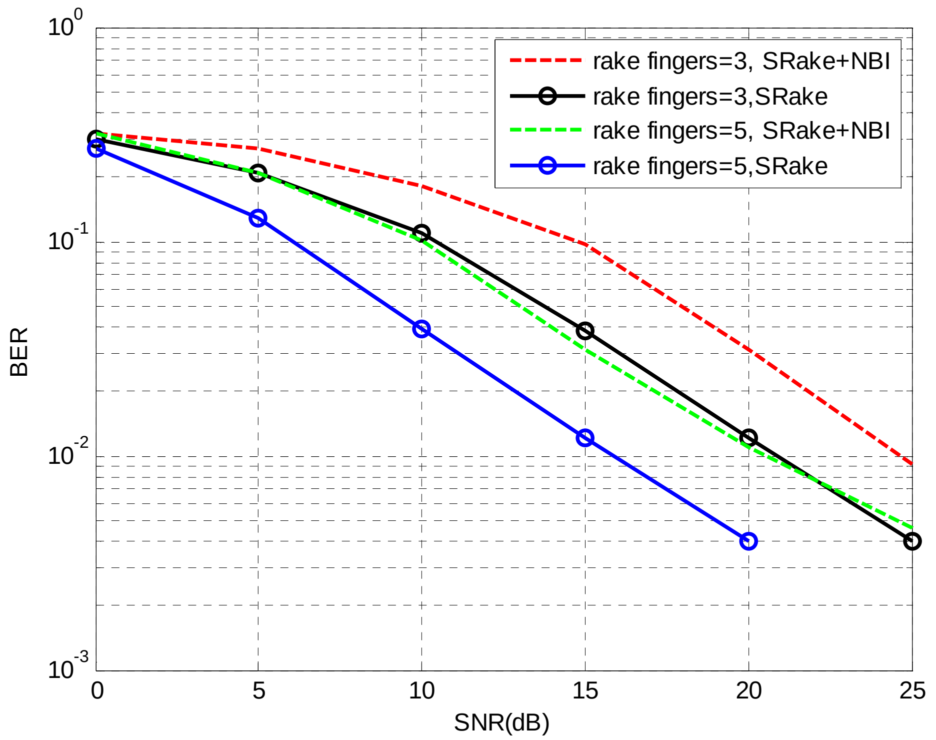


Fig. 3.5 Performance of SRake receiver for CM1 channel model

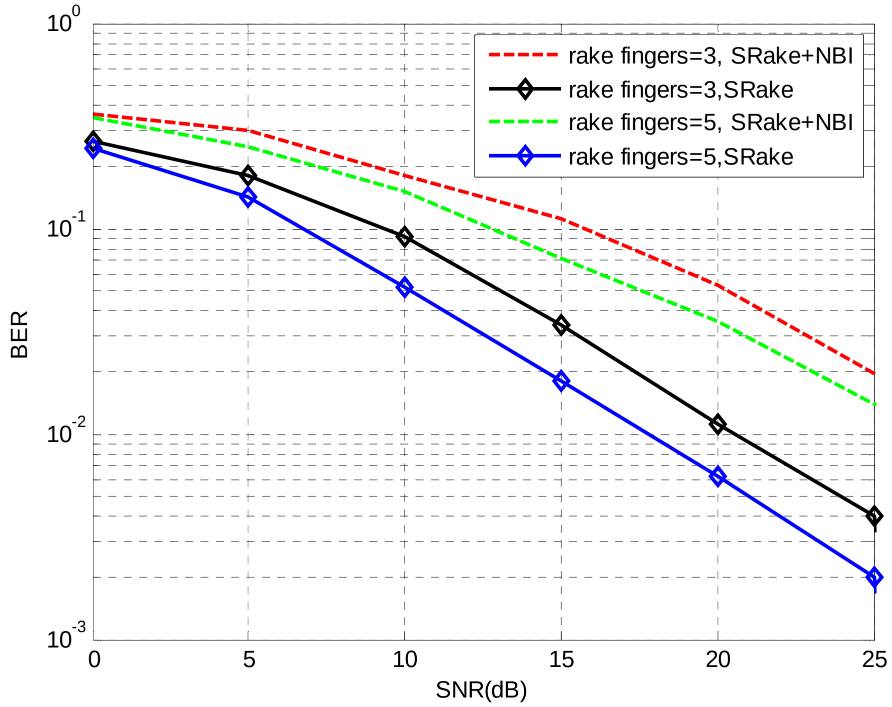


Fig. 3.6 Performance of SRake receiver for CM2 channel model

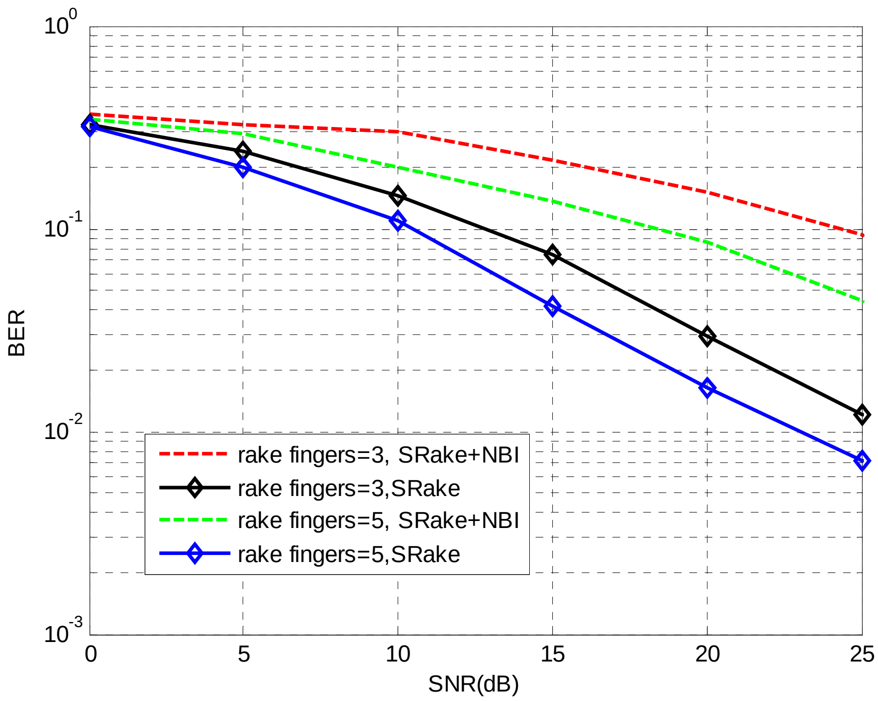


Fig. 3.7 Performance of SRake receiver for CM3 channel model

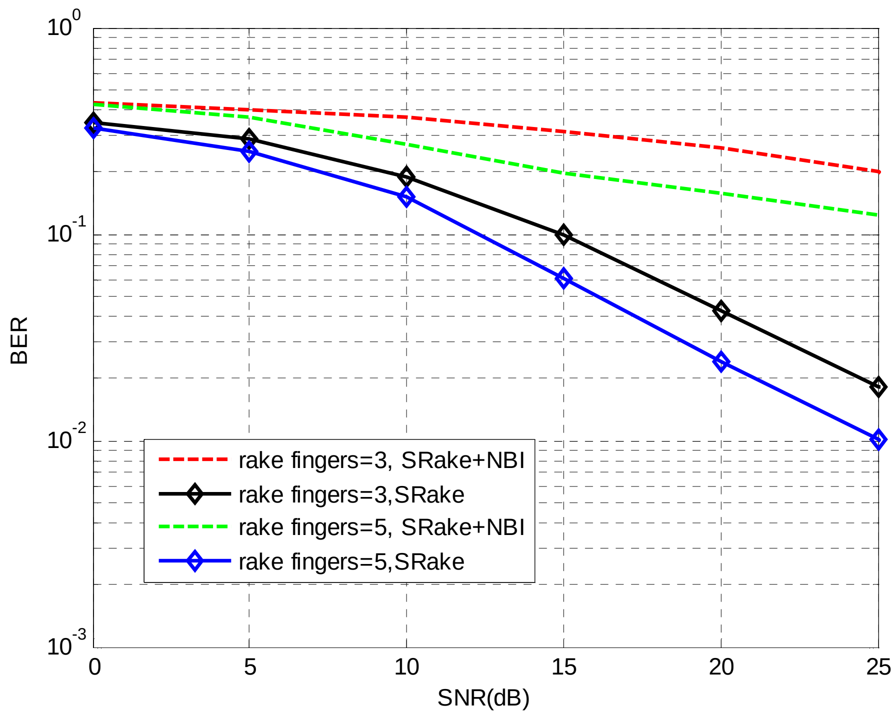


Fig. 3.8 Performance of SRake receiver for CM4 channel model

However, as discussed before with increase in rake fingers the performance of SRake receiver increases. When the number of rake fingers is increased to 5, similar degradation in performance is noticed in both CM1 LOS channel medium and in CM2 NLOS channel medium as shown in Fig. 3.6. As shown in Fig. 3.7 for CM3 channel model, at SNR=20dB, UWB SRake receiver bit error rate (BER) passes from 1.2×10^{-2} to 0.95×10^{-2} for 3 number of rake fingers and from 0.7×10^{-2} to 0.44×10^{-1} for 5 number of rake fingers under the effect of NBI. The performance of SRake receiver in presence of NBI is almost over the 10^{-1} BER floor. The receiver structure cannot mitigate NBI and hence the performance deteriorates. So it is concluded as the multipath is reasonably high for CM3 and CM4 channel models, Rake receiver structure performance fails to eliminate NBI alone.

3.6. UWB SRAKE-MMSE RECEIVER STRUCTURE

A hybrid SRAKE-MMSE receiver structure for high data rate UWB system is studied by the advantages of both rake fingers and equalizer taps. A major advantage of MMSE scheme relative to other interference suppression scheme is that explicit knowledge of interference parameter is not required [29] and [36]. The receiver structure is illustrated in Fig. 3.9 and consists in a SRake receiver followed by a linear MMSE equalizer. The received signal first passes through the receiver filter matched to the transmitted pulse. The output of the receiver filter is sampled at each rake finger [26]. The minimum rake finger separation is $T_m = T_s / N_u$, where N_u is chosen as the largest integer value that would result in T_m spaced uncorrelated noise samples at the rake fingers. For general selection combining, the rake fingers (β's) are selected as the largest L $(L \le N_u)$ sampled signal at the matched filter output within one symbol time period at time instants $\tau_l^{'}$, l = 1, 2, ..., L.

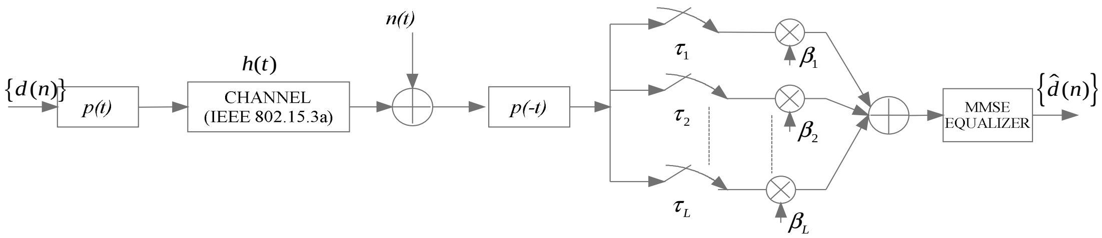


Fig. 3.9 UWB SRAKE-MMSE receiver structure

For a minimum mean square error (MMSE) SRake receiver, the conventional finger selection algorithm is to choose the paths with highest signal-to-interference-plus-noise ratios (SINRs) [66]. The noiseless received signal is given by equation (3.5). As derived in section 3.2, Rake combiner output at time $t = n.T_s$ is

$$y[n] = \sum_{l=1}^{L} \beta_l v\left(n.T_s + \tau_l^{'}\right) + \sum_{l=1}^{L} \beta_l \hat{n}\left(n.T_s + \tau_l^{'}\right) \tag{3.9}$$

Assuming that the n^{th} data bit is being detected, the MMSE criterion consists in minimizing

$$E\left[\left| d(n) - \hat{d}(n) \right|^2\right] \tag{3.10}$$

where $\hat{d}(n)$ is the equalizer output. From the Rake output signal, the desired signal, the undesired ISI and the noise are distinguished as

$$y(n)=\left[\sum_{l=1}^{L}\beta_l \tilde{h}(\tau_l^{'})\right]d(n)+\sum_{k\neq n}\sum_{l=1}^{L}\beta_l \tilde{h}\left(\left(n-k\right).T_s+\tau_l^{'}\right)d(k) \\ +\sum_{l=1}^{L}\beta_l \hat{n}\left(n.T_s+\tau_l^{'}\right) \tag{3.11}$$

where the first term represents the desired output. The noise samples at different fingers, $\hat{n}(n.T_s+\tau_l^{'})$, l = 1... L, are uncorrelated and therefore independent, since the samples are taken at approximately the multiples of the inverse of the matched filter bandwidth. It is assumed that the channel has a length of (n_1 + n_2 + 1).T_s. That is, there is pre-cursor ISI from the subsequent n_1 symbols and post-cursor ISI from the previous n_2 symbols, and n_1 and n_2 are chosen large enough to include the majority of the ISI effect [40] and [48]. Using (3.11), the Rake output can be expressed now in a simple form as

$$y(n)=\alpha_0.d(n)+\sum_{\substack{k=-n_1\\k\neq 0}}^{n_2}\alpha_k.d(n-k)+\tilde{n}(n)=\phi^T[n]+\tilde{n}(n) \tag{3.12}$$

where

$\phi=[\alpha_{n_1}\ldots\alpha_0\ldots\alpha_{n_2}]$ and $d[n]=[d(n+n_1)\ldots d(n)\ldots.d(n-n_2)]^T$ .Coefficient of α_K's are obtained by matching (3.11) and (3.12). The noise at Rake output is $\tilde{n}(n)=\sum_{l=1}^{L}\beta_l \hat{n}$ (n.Ts + $\tau_l^{'}$). The output of the linear equalizer (LE) is obtained as

$$\hat{d}(n)=\sum_{r=-k_1}^{k_2}c_r.y\left(n-r\right)=c^T\gamma\left(n\right)+c^T\eta\left(n\right) \tag{3.13}$$

where c =[c_{K1} ...c_0 ...c_{K2}] contains the equalizer taps. Also

$$\gamma[n]=\left[\phi^T d\left[n+K_1\right]...\phi^T d\left[n\right]...\phi^T d\left[n-K_2\right]\right]^T \tag{3.14}$$

$$\eta\left[n\right]=\left[\tilde{n}\left(n+K_1\right)\ldots\tilde{n}\left(n\right)\ldots\tilde{n}\left(n=K_2\right)\right]^T \tag{3.15}$$

The mean square error (MSE) of the equalizer,

$$E\left[\left|d(n) - c^T \gamma[n] - c^T \eta[n]\right|^2\right] \tag{3.16}$$

Equation (3.16) is a quadratic function of the vector *c*, has a unique minimum solution. Defining matrices R, p and N as

$$\mathbf{R} = E\left[\gamma[n].\gamma^T[n]\right] \tag{3.17}$$

$$\mathbf{p} = E\left[d(n).\gamma[n]\right] \tag{3.18}$$

$$\mathbf{N} = E\left[\eta[n].\eta^T[n]\right] \tag{3.19}$$

The equalizer taps are given by

$$c = (R+N)^{-1}.p \tag{3.20}$$

and the MMSE is

$$J_{\min} = \sigma_d^2 - p^T (R+N)^{-1}.p \tag{3.21}$$

$$\sigma_d^2 = E[|d(n)|^2]$$

This Rake equalizer receiver will eliminate ISI as far as the number of equalizer's taps gives the degree of freedom required.

The equalizer output can be expressed as

$$\hat{d}(n) = q_0.d(n) + \sum_{i=0} q_i.d(n-i) + w(n) \tag{3.22}$$

with $\quad q_n = \alpha_n.c_n$

The variance of *w(n)* is

$$\sigma_{w(n)}^2 = \left(\sum_{i=-K_1}^{K_2} c_i^2\right)\left(\sum_{l=1}^{L} \beta_1^2\right).E_p.{}^{N_0}\!/_2 \tag{3.23}$$

where E_p is the pulse energy. In the case of decision feedback equalizer (DFE), assuming error free feedback, the input data vector can be written in the form of

$$\gamma_{DFE}[n] = [\Phi^T d[n+K_1]...\Phi^T d[n] \;\; d[n-1]...d[n-K_2]] \tag{3.24}$$

Using the same approach as for the linear equalizer, the MMSE feed forward taps for the DFE equalizer are obtained.

3.7. UWB SRAKE-MMSE RECEIVER IN PRESENCE OF NBI

A narrow band interference model, that is generally WLAN, which coexists with UWB signal at the frequency 5.25 GHz as, provided in (3.7). The received signal sampled at the l^{th} rake finger in the n^{th} data symbol interval given by equation (3.7).

The Rake combiner output [26] at time $t = n.Ts$ is

$$y[n] = \sum_{l=1}^{L} \beta_l . v\left(n.T_s + \tau_l^{'}\right) + \sum_{l=1}^{L} \beta_l . i\left(n.T_s + \tau_l^{'}\right) + \sum_{l=1}^{L} \beta_l . \hat{n}\left(n.T_s + \tau_l^{'}\right) \quad (3.25)$$

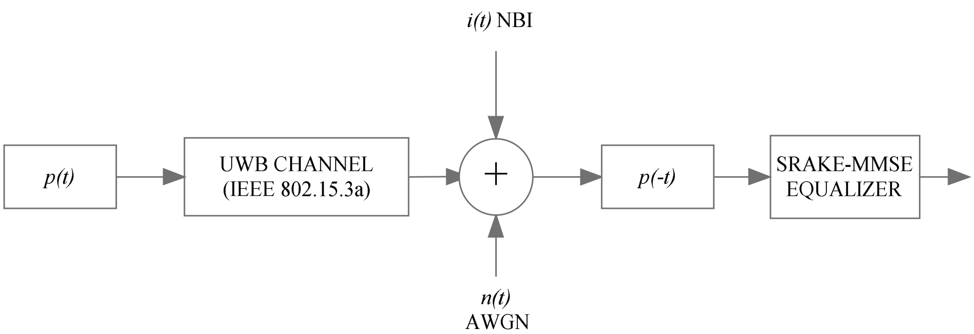


Fig. 3.10 UWB RAKE-MMSE receiver structure with NBI

The received signal is sampled at pulse repetition frequency after passing through the correlation receiver. The samples are linearly combined using the MMSE criterion, so that weights are effective to suppress the NBI [36]. The MMSE weight vector c^* is given by

$$c^* = (R_S + R_I + R_N)^{-1}.p \quad (3.26)$$

where R_S, R_I, R_N are the autocorrelation of the signal, the NBI and the noise respectively. So The MMSE can be mathematically expressed as

$$J_{\min} = \sigma_d^2 - p^T (R_S + R_I + R_N)^{-1}.p \quad (3.27)$$

$$\sigma_d^2 = E[|d(n)|^2] \quad (3.28)$$

Thus, it is concluded that in the NBI suppression analysis using SRAKE-MMSE receiver, the correlation between the samples of the received signal plays the main role. Assuming *n(t)* is not correlated to *i(t)* and has an impulsive auto-correlation, Hence the NBI is modeled as single tone.

3.8 SIMULATION STUDY AND RESULTS

3.8.1 Performance analysis of SRAKE-MMSE receiver in UWB system

Performance of hybrid SRAKE-MMSE equalizer receiver for high data rate UWB system is investigated through MATLAB simulation. In the evaluation of receiver performance, high multipath UWB propagation channel models, i.e. CM3 and CM4 are considered. In UWB SRAKE-MMSE receiver design, selection of the number of rake fingers and the length of equalizer taps play a main role. The rake fingers are regularly positioned according to time channel spread and the number of fingers [66].

The pulse shape adopted in the simulation study is taken as the second derivative of the Gaussian pulse with pulse width 0.35 nsec. The root raised cosine (RRC) pulse with roll off factor α=0.5 is used in the pulse-shaping filter. An oversampling factor of eight is used for the root raised cosine (RRC) pulse According to this sampling rate, time channel spread is chosen equal to 100 for CM4 and 70 for CM3, this corresponds to respectively 12 =100 / 8 and 9 = 70 / 8 transmitted symbols. This choice enables to gather 99% of the channel energy. The coherence bandwidths of CM3 and CM4 simulation are 10.6 MHz and 5.9 MHz respectively. The data rate is chosen to be 200 Mbps resulting in symbol duration of 5 nsec. The simulation is performed at 100.8 GHz sampling rate. The rake finger minimum time spacing is chosen as 0.1786 nsec, for N_u = 28. Each channel is normalized prior to multiplying it by the shadowing factor. The transmitter pulse shape has unit energy. The size of the transmitted packets is equal to 2560 BPSK symbols including a training sequence of length 500. CIR remains constant over the time duration of packet. Table 3.1 provides all the simulation parameter used for SRAKE-MMSE receiver. Performance of UWB SRAKE-MMSE receiver varying length of equalizer taps and rake fingers for CM3 and CM4 as shown in Fig. 3.11 and 3.12.

Table 3.1 Simulation Parameter for SRAKE-MMSE receiver

Parameter	Values
Data rate	200 Mbps
Pulse width	0.35 ns
Symbol duration	5ns
Pulse energy	1
T_m	0.1786 ns
N_u	28
Channel spread	CM3=70, CM4=100
Pilot carrier	500

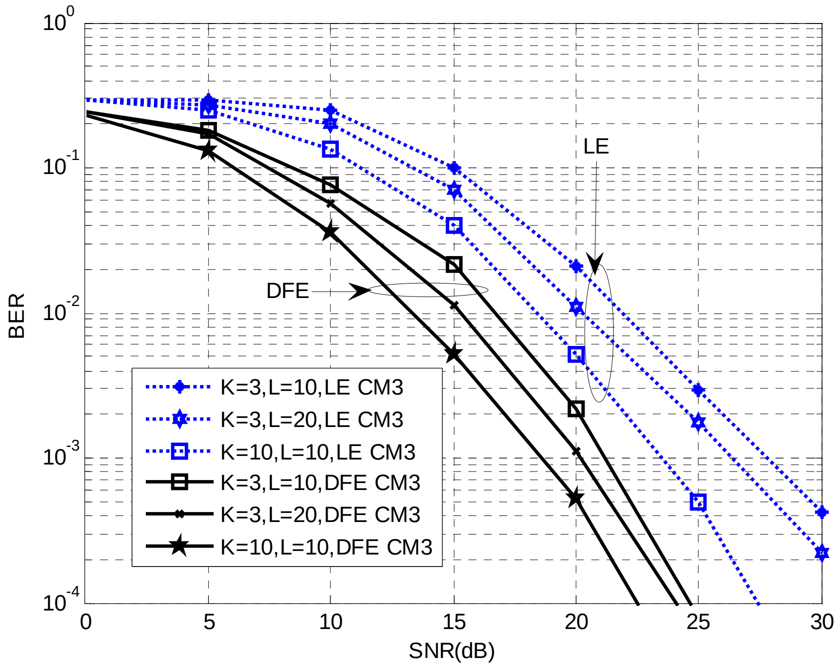


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Fig. 3.11 Performance of UWB SRAKE-MMSE-receiver for different length of equalizer taps and rake fingers for CM3 channel model

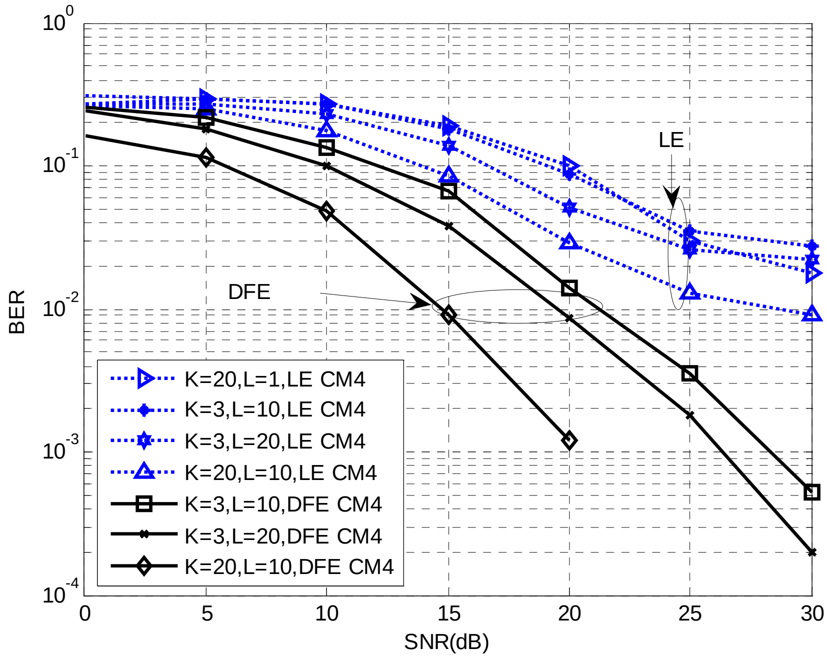

Fig. 3.12 Performance of UWB SRAKE-MMSE-receiver for different length of equalizer taps and rake fingers for CM4 channel model

Fig. 3.11 shows that keeping the number of rake fingers constant (K=3), almost 1dB SNR gain at a BER level of 10^{-3} is observed with increase in length of equalizer taps from L=10 to 20. Whereas keeping the number of equalizer taps same (L=10), around 4dB SNR improvement is obtained increasing the rake fingers from K=3 to 10. Further decision feedback equalizer (DFE) provides more than 5dB SNR improvement than that of linear equalizer (LE) for K = 10, L = 10 in case of CM3 channel model. The performance improvement is noticeable when the number of rake fingers and the equalizer taps are simultaneously increased to K = 20 and L = 10 as shown in Fig. 3.12. Comparing the BER performances, it is observed that on different UWB NLOS channel models (CM3 and CM4) LE fails to perform satisfactorily at high SNR’s due to presence of zeros outside the unit circle. These difficulties are overcome by using DFE of same filter length. A DFE outperforms a linear equalizer of the same filter length, and the performance further improves with more equalizer tap length. At high SNR’s, ISI affects the system performance, where at low SNR’s the system noise degrades the performance. So receiver with more number of rake fingers outperforms the one that has more equalizer taps at high SNR condition.

3.8.2 Performance analysis of SRAKE-MMSE receivers for NBI mitigation in UWB system

It is already studied in section 3.5 that UWB system performance degrades due to interferers from narrowband system. If NBI is not suppressed, the receiver may be jammed also. For suppression of NBI, the SRAKE-MMSE receiver structure is studied using the same UWB cannel models. The simulation is analyzed using SRake with 5 fingers and number of equalizer taps are 20 and an NBI with an SIR=-20dB. The parameters are set as discussed in section 3.8.1.

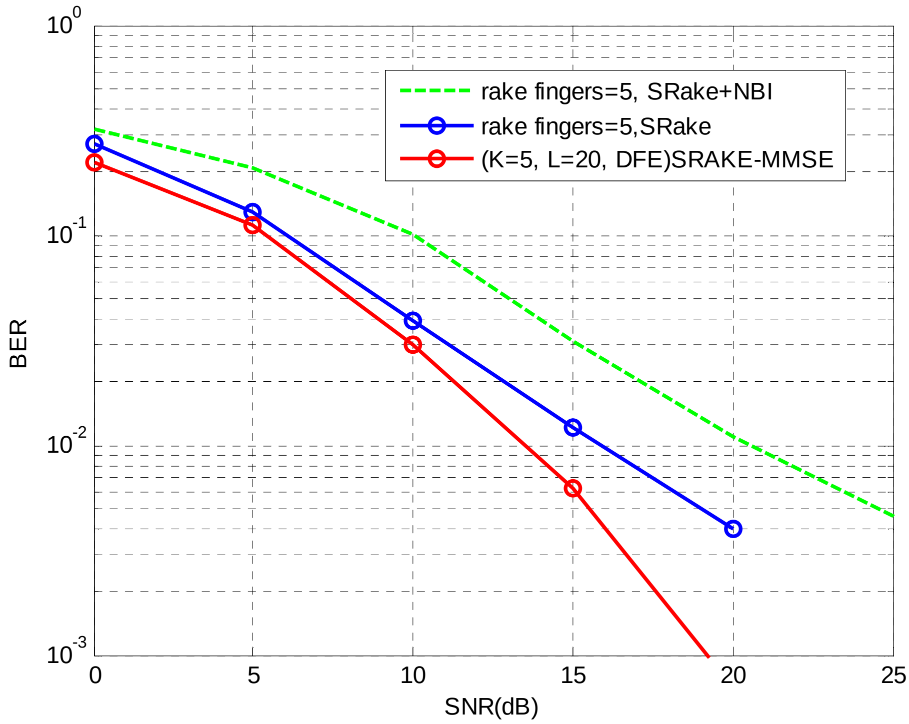

Fig. 3.13 Performance of SRAKE-MMSE receiver with NBI for CM1 channel model

Fig. 3.13 shows the UWB SRAKE-MMSE receiver bit error rate (BER) performance improves even in presence of NBI, gaining almost 8dB SNR at BER = 10^{-2}. Fig. 3.12 provides the BER vs. SNR performance for CM2 channel model. From low to medium SNR, it is observed that UWB SRAKE-MMSE performs almost the same as UWB SRake receiver to alleviate the effect of NBI. But at high SNR, almost 9dB SNR improvement is observed in UWB SRAKE-MMSE receiver due to the MMSE equalizer which compensates the effect of ISI.

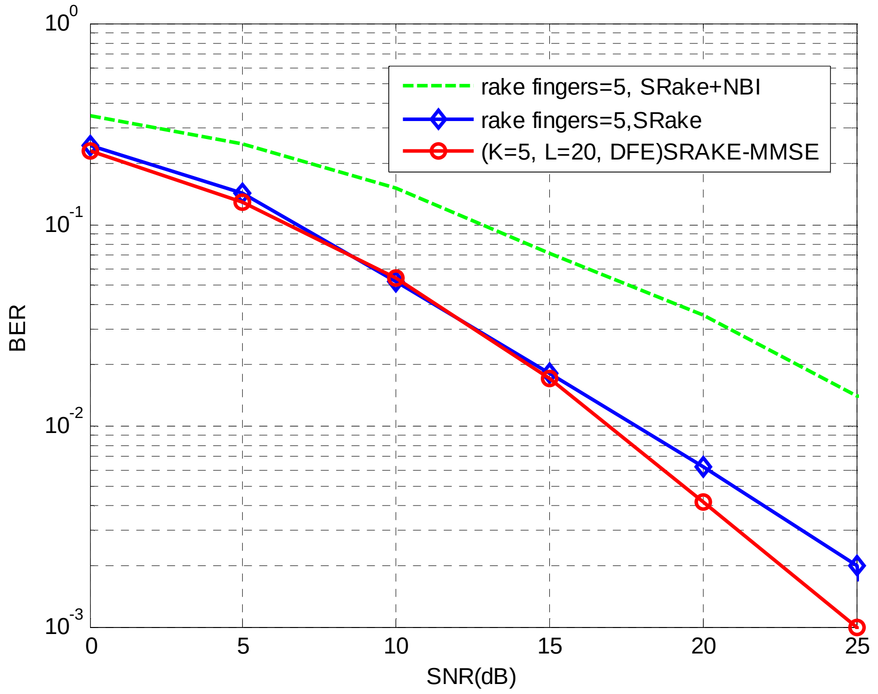

Fig. 3.14 Performance of SRAKE-MMSE receiver with NBI for CM2 channel model

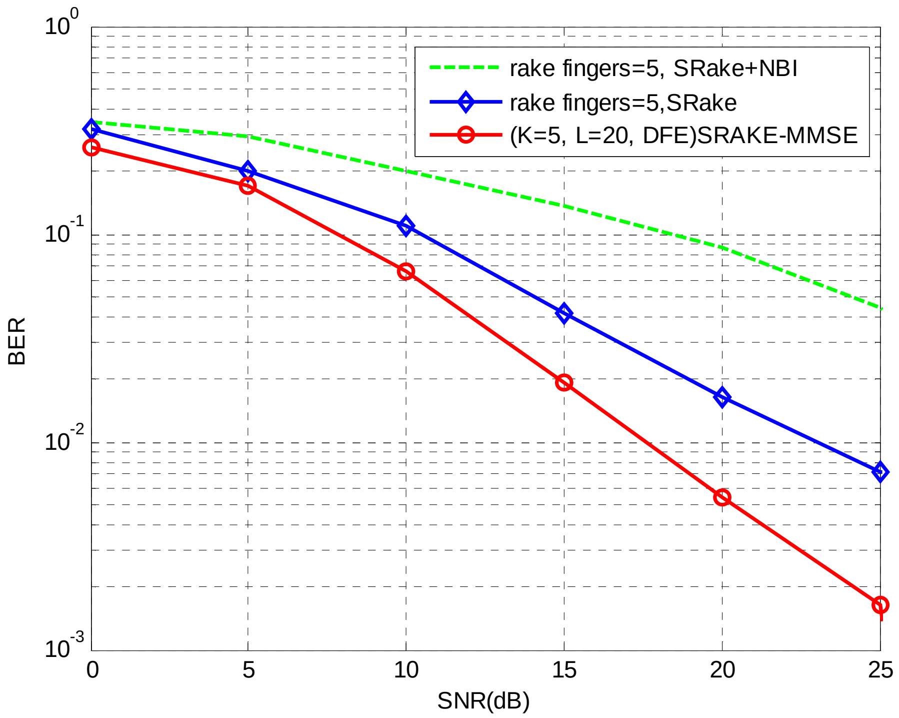

Fig. 3.15 Performance of SRAKE-MMSE receiver with NBI for CM3 channel model

Similar effects in performance are observed for CM3 and CM4 models also. Table 3.2 describes the improvement in BER level at SNR =20dB.

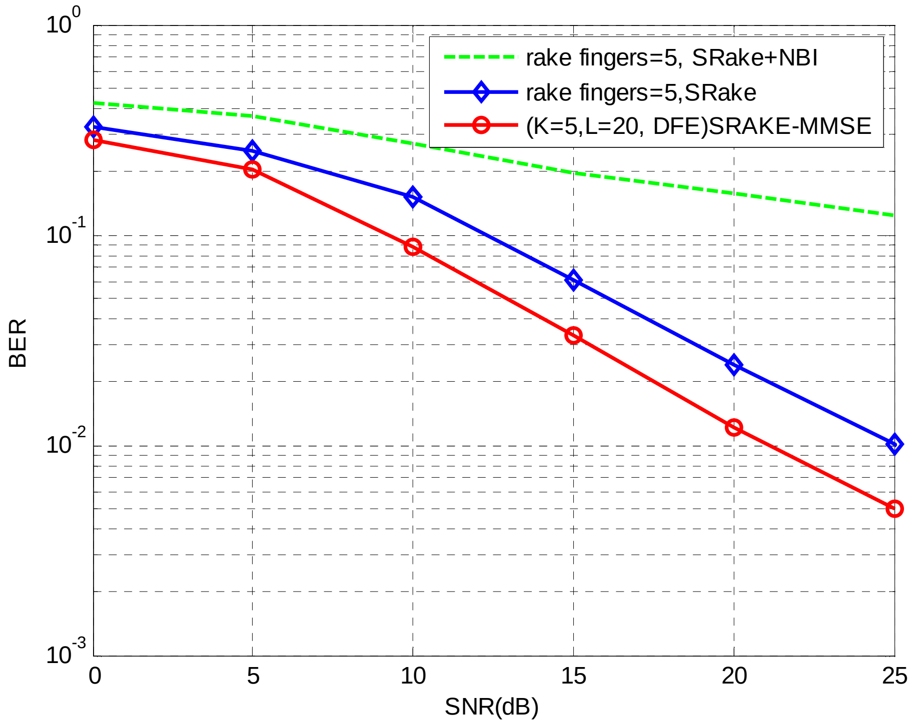

Fig. 3.16 Performance of SRAKE-MMSE receiver with NBI for CM4 channel model

Table 3.2 Improvement in BER level at SNR=20dB

Receiver structure	UWB SRAKE-MMSE Receiver in presence of NBI (SIR=-20dB)	UWB SRake receive in presence of NBI (SIR=-20dB)
UWB Channel models	BER	BER
CM1	$<< 0.1\times10^{-2}$	0.11×10^{-1}
CM2	0.4×10^{-2}	0.36×10^{-1}
CM3	0.5×10^{-2}	0.88×10^{-1}
CM4	0.12×10^{-1}	0.155×10^{0}

From this study, it can be concluded that UWB SRAKE-MMSE receiver is effectively robust against the NBI by taking the benefit of rake finger and equalizer taps.

3.9 CONCLUSION

IR-UWB is an emerging as a solution for the IEEE 802.15a (TG3a) standard, which provides low complexity, low cost, low power consumption and high data-rate in Wireless Personal Area Network (WPAN) system. For high data rate and short range, the receiver combats NBI interference by taking advantage of the Rake receiver and MMSE equalizer structure. MMSE equalizer operating at low to medium SNR’s, the number of rake fingers is the dominant factor to improve system performance, while at high SNR’s the number of equalizer taps plays a significant role. From implementation point of view, the proposed narrowband interference suppression technique based upon SRake followed by MMSE equalizer is costly and more complex.

Chapter 4

Proposed Interference mitigation techniques in TR-UWB WPAN systems

PROPOSED INTERFERENCE MITIGATION TECHNIQUES IN TR-UWB WPAN SYSTEMS

4.1 Introduction

The Impulse Radio (IR) UWB concept relies on the transmission of a train of data pulses, each with very small duration in order of nanoseconds occupying a bandwidth of few gigahertz [8] and [22]. In this system Rake, SRAKE-MMSE receivers are the sub optimal demodulation schemes as the multipath diversities are automatically achieved [66]. However, from implementation point of view without information of number of rake fingers and MMSE equalizer taps accurate acquisition and channel estimation seems to be complex and difficult [41], [42], [44] and [45]. Further, for high data rate UWB system, orthogonality between each of the signals in various rake fingers is an invalid assumption, which leads to inter symbol interference (ISI) [45] and [48]. To overcome these aforementioned problems associated with IR-UWB system, a suboptimal low complexity transmitted reference (TR) autocorrelation receiver (AcR) [63] is proposed by Hoctor and Talminson [50] and [51]. TR-UWB receivers are popular for their simplicity, capability to reduce the strongest UWB timing requirements and robust performance in multipath channels [34], [35] and [44]. The transmitted reference refers to the transmission of both data modulated pulse and an unmodulated pulse which is used as 'reference' for signal demodulation simultaneously. In a TR modulation format, a reference pulse is transmitted before each data modulated pulse. At AcR front end, the reference pulse is time aligned through a delay line with the data pulse [47]. Required level of energy for transmitted data detection is obtained through correlation of those two pulses over a certain integration time. Since both the pulse undergo the same channel distortion and reference signal is used as estimate of the multipath channel response [71]. Thus channel estimation constraint is greatly relaxed as the noisy estimate of channel can be directly obtained from received signal. The advantage of using TR-UWB over IR-UWB are to use all the energy of the data signal without requiring additional channel estimation and synchronization procedure is considerably simplified without using Rake reception [46].

Performance of TR receiver is considerably limited by severity of channel noise such as additive white Gaussian noise and strong NBI from coexisting narrowband wireless systems on the transmitted signal which affect the data pulse and reference pulse equally [42]. Narrowband interferers may have less energy is concentrated over a narrow bandwidth, they can mask low power UWB signals and performance suffer considerably in the presence of strong NBI. Researchers have proposed several techniques to mitigate these interferences. If the statistics regarding interference are known then the system can avoid interference by adjusting both transmitter and receiver parameters. Here two techniques are devised improving the performance of UWB system by suppressing the interference from and to the UWB signals. First by using appropriate pulse shaping at the UWB transmitter side such that there is no emission in overlapping band and second one by modifying the TR-UWB receiver side [49].

Section 4.2 introduces the TR-UWB communication system. In section 4.3, effect of interferences in TR-UWB system is analyzed and Section 4.4 explains the two mitigation techniques. The pulse shaping analysis and simulation results are presented in section 4.4.1 Modified TR-UWB receiver cancellation scheme is investigated in section 4.4.2 Simulation results are analyzed in section 4.5. The conclusion is presented in section 4.6.

4.2 TRANSMITTED REFERENCE UWB COMMUNICATION SYSTEM

For UWB communication channels are highly dispersive in nature and so the channel estimation is a very challenging task. Designing a receiver that generates reference locally at the receiver, estimates the channel, and captures enough energy for data detection is a difficult task. Instead of locally generating it, the reference signal can be transmitted along with the information data. Such a system is known as transmitted reference (TR) system. TR signaling was used for military spread spectrum communication initially. TR has regained popularity in UWB communication systems TR-UWB system is a simple receiver structure, which captures all of the energy available in a UWB multipath channel for demodulation at the receiver [34] and [35]. Further TR is a correlation receiver system, thus it does not require channel estimation and has weak dependence on distortion [45], [63], [69] and [71]. The major drawback of this system is the use of noisy template for demodulation, which can be overcome by an autocorrelation receiver that averages previously received reference pulses to suppress noise. TR signaling for an UWB system with AcR can exploit multipath diversity inherent in the environment [71]. By using the AcR, synchronization procedure is also considerably simplified. Due to suboptimal signal template taken from received signal, increased noise and interference power become a major drawback [42]. The system model for the transmitted reference system [63] is presented in Fig. 4.1.

A mathematical representation of UWB transmitted signal $s_{tr}(t)$ is [68]

$$s_{tr}(t) = \sqrt{E_w} \sum_{n=-\infty}^{\infty} p(t - nT_d) + a_n p\left(t - nT_d - D_{n \bmod N_d}\right) \tag{4.1}$$

Where $p(t)$ is denoted as pulse having a duration of T_w of few hundred picoseconds. The transmitted pulse shape has unity energy and is given by $\int p^2(t)dt = 1$ The symbol energy is divided into N_d doublets, each one consists of two pulses delayed in time D_j nanosecond. D_j is referred to as delay hopping code $D_j > T_w + T_h$, $j = 0.......N_d - 1$. T_h is known as the duration of UWB multipath channel $h_{UWB}(t)$.

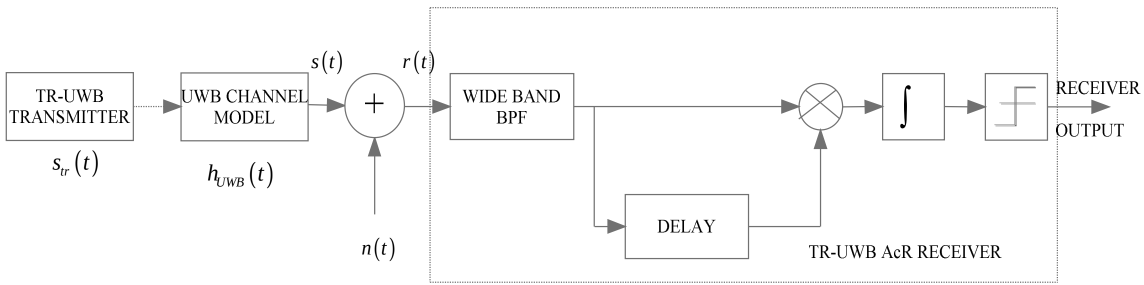

Fig. 4.1 TR-UWB communication system model

Each doublet pulse is repeated every T_d nsec, with $T_d > \left(T_w + T_h + \max D_j\right)$ to avoid interference between adjacent doublet. The first pulse of each doublet is used as signal template for demodulation of the data conveyed by second pulse. The amplitude of modulated pulse is expressed as $a_n = d_{\lfloor n/N_d \rfloor} b_{n \quad \mathrm{mod N_d}}$, where, $d_{\lfloor n/N_d \rfloor} = \{1, -1\}$ represents binary data set.

The UWB channel is modeled as $h_{UWB}(t)$

$$h_{UWB}(t) = \sum_{l=0}^{L-1} h_l \delta(t - t_l) \tag{4.2}$$

where the total number of multipath is L, h_l represents the amplitude for l^{th} path and t_l is denoted as arrival time for l^{th} path.

At the channel output, the UWB signal is represented as

$$s(t) = s_{tr}(t) * h_{UWB}(t) \tag{4.3}$$

The received signal is represented as

$$r(t) = s(t) + n(t) \tag{4.4}$$

where, $n(t)$ is additive white Gaussian noise with power spectral density $N_0/2$. Received UWB signal equation (4.3) can be rewritten as

$$s(t) = \sqrt{E_w} \sum_{j=0}^{\mathrm{N}_d - 1} g(t - jT_d) + a_j g(t - jT_d - D_j) \qquad (0 \le t \le N_d T_d) \tag{4.5}$$

$$g(t) = p(t) * h_{UWB}(t) \tag{4.6}$$

The receiver consists of N_d branches, each one provided with a delay-line matched to one of the elements of the delay hopping code D_j and with an integrator.

The output of the receiver branch j is described by

$$Z_j = \int_{jT_d}^{jT_d + T_1} r(t)\, r(t + D_j)\, dt \tag{4.7}$$

The data modulated pulse is then correlated with data unmodulated pulse, which provides a noisy estimation of UWB channel response.

All the outputs Z_j are then coherently combined to form the decision variable.

$$Z = \sum_{j=0}^{\mathrm{N}_d - 1} b_j Z_j = d\phi + n \tag{4.8}$$

where, the useful energy for data detection is given by

$$\phi = N_d E_w \int_0^{T_1} g^2(t) dt \tag{4.9}$$

Signal $g(t)$ is a stochastic process, Noise term n can be modeled as a Gaussian random variable with zero mean term and variance.

$$\sigma_n^{\ 2} = N_0\left(\phi + TW(N_0/2)\right) \tag{4.10}$$

where $T = T_1 N_d$ is the overall integration time for symbol detection.

The bit error probability is given by

$$P\left(e/\phi\right) = Q\left(\phi/\sigma_n\right) \tag{4.11}$$

4.3 EFFECT OF INTERFERENCES IN TR-UWB SYSTEM

The UWB signal must be kept under the spectral mask provided by regulations so that it will not damage the coexisting wireless systems and vice versa. However, the Gaussian monocycle pulses need to be filtered to meet the FCC spectral mask. Although the pulses designed in the aforementioned methods meet FCC spectral mask properly, and well suppress the single narrowband interference (NBI), but are unable to suppress the multiple narrowband interference (m-NBI) and wideband interference (WBI) situation[42], [43], [44], [46] and [47], .

In this section the interference effects are theoretically investigated in a TR-UWB system using auto correlation receiver [46], [47] and [68]. It is convenient to model the interference at the UWB receiver front-end as a single tone sinusoidal signal [68].

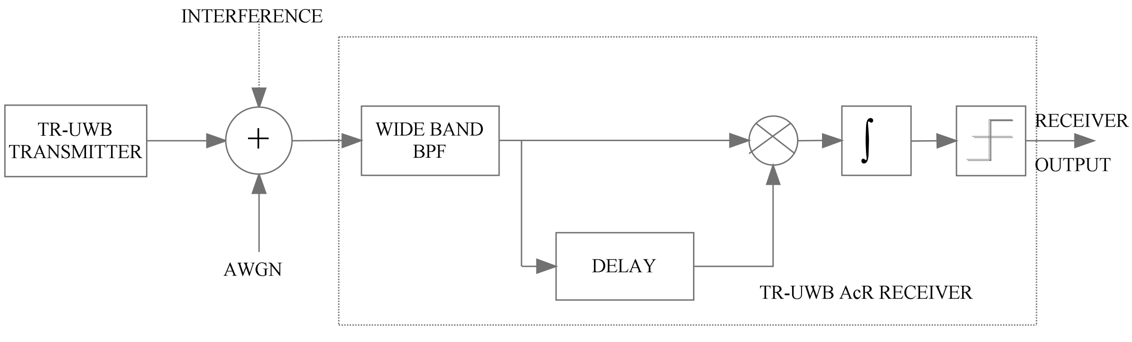

Fig. 4.2 TR-UWB Transceiver Model in presence of interference

The narrowband interference (NBI) signal is modeled as a traditional single carrier BPSK modulated waveform, as discussed in section 3.3 and given by [68]

$$i\left(t\right) = \sqrt{2P_I}\cos\left(\omega_0 t + \theta\right)\sum_{p=-\infty}^{\infty} g_k Z(t - kT_1 - \tau_1) \tag{4.12}$$

The decision variable equation in (4.8) explained in section 4.2 is modified considering the narrowband interfering signal $i(t)$

$$Z = \sum_{j=0}^{N_d-1} b_j \int_{jT_d}^{jT_d+T_1} \left[r(t)+i(t)\right]\left[r\left(t+D_j\right)+i\left(t+D_j\right)\right]dt \tag{4.13}$$

$$Z = \phi + n + \chi \tag{4.14}$$

Where, χ is extra nuisance term due to narrowband interfering signal. Decomposing χ into three parts.

$$\chi = x_{gi} + x_{ii} + x_{ni} \tag{4.15}$$

$$x_{gi} = \sqrt{E_w}\sum_{j=0}^{N_d-1} b_j \int_0^{T_1} g(t) i\left(t + jT_d + D_j\right)dt + \sqrt{E_w}\sum_{j=0}^{N_d-1} b_j a_j \int_0^{T_1} g(t) i\left(t + jT_d\right)dt \tag{4.16}$$

$$x_{ii} = \sum_{j=0}^{N_d-1} b_j \int_{jT_d}^{jT_d+T_1} i(t) i\left(t+D_j\right)dt \tag{4.17}$$

$$x_{ni} = \sum_{j=0}^{N_d-1} b_j \int_{jT_d}^{jT_d+T_1} \left[n(t) i\left(t+D_j\right) + i(t) n\left(t+D_j\right)\right]dt \tag{4.18}$$

Narrowband interference gives rise to extra interference terms, namely x_{gi} and x_{ii}.

The term x_{ni} represents an extra noise term due to noisy signal template.

Finally the performance of TR-UWB receiver are given by

$$\mathrm{P}\left(e/\phi,\beta\right) = \frac{1}{2}Q\left(\frac{\phi + x_{ii}}{\sqrt{\sigma_n^{\ 2} + \sigma_x^{\ 2}}}\right) + \frac{1}{2}Q\left(\frac{\phi - x_{ii}}{\sqrt{\sigma_n^{\ 2} + \sigma_x^{\ 2}}}\right) \tag{4.19}$$

where

$$\sigma_x^{\ 2} = P_I\left(E_s\left|G(f_i)\right|^2 + N_0 T\right) \tag{4.20}$$

$$G(t_i) = \left|G(f_i)\right| e^{i\theta_G} \tag{4.21}$$

(4.21) is the Fourier transform of $g(t)$ computed at frequency $f = f_i$. E_s is the transmitted energy per symbol. Thus it is concluded through analysis, presence of narrowband interference or wideband interference increases both noise power and also adds a extra interference terms which can severely deteriorate the performance.

4.4 PROPOSED TECHNIQUE FOR INTERFERENCE SUPPRESSION IN TR-UWB SYSTEM

Improving the transceiver by suppression of interference when the systems coexist with other spectrally overlapping narrowband wireless system. TR-UWB are susceptible to NBI because the interference will be multiplied at the AcR's end. Hence the system needs improvement to counteract the interferers. Further Interference reduction from UWB systems to other narrowband (single and multiple) and wideband systems and vice versa are to be considered [49].

Narrow band interference (NBI) signal interference at 5.25 GHz is the slaughterer to UWB system whereas wideband interference (WBI) signals coexist with UWB system at 7.5GHz. Suppression of interference level using two different strategies is attempted in this research work such as:

- UWB Pulse Design: Interference is avoided without using the frequency band where the interferer operates. Multi-resolution Eigenvalue decomposition technique is used for performing desired pulse shaping to the UWB signal. The transmitted waveform shape is designed properly, such that the transmission at some specific frequencies is omitted such that interference from UWB to other NB, multiple NB and wideband system is reduced [49] and [65].
- Modified TR-UWB Receiver: Suppression of interference to the UWB system is done by introducing a notch filter at the UWB autocorrelation (AcR) receiver. So that interference from other wireless systems to UWB system is mitigated [43] and [68].

The proposed technique does not reduce the capacity of the UWB system even the data rate changes from low to high data rate and hence ISI can be overcome [48]. Performance of these proposed techniques are investigated using MATLAB simulation.

4.4.1 UWB Pulse Design using Eigenvalue decomposition technique

Interference reduction from UWB systems to other narrowband and wideband systems can be done using pulse shaping technique. The UWB signal is divided into a number of pulses to increase the flexibility and to reduce the sensitivity to interference by splitting the frequency spectrum into sub-bands [57]. The total UWB signal is the sum of all pulses as each pulse has a different center frequency having the same pulse width. Data can be transmitted through all the sub-bands or through only selected number of them. In the case of coexistence with other interference system such as narrowband interference (NBI), multiple narrowband interference (m-NBI) and wideband interference (WBI), a number of UWB sub-bands centered on the interferer can be removed [65]. This was achieved using Eigenvalue decomposition model for UWB pulse design. The same UWB pulse can be used to perform a multi-resolution analysis of a transmitted UWB waveform into multiple sub-bands pulses centered on set of different subcarriers.

UWB pulse design method was first presented in [64]. Design of UWB pulse uses the Eigenvalue decomposition model.

The FCC desired spectral mask is given by

$$H(f) = \begin{cases} 1 & f_L < f < f_H \\ 0 & elsewhere \end{cases} \tag{4.22}$$

where f_L = 3.1GHz, f_H=10.6GHz.

The corresponding inverse Fourier transform is represented as

$$h(t) = 2 f_H \sin c(2 f_H t) - 2 f_L \sin c(2 f_L t) \tag{4.23}$$

The frequency response of a filter is decided based on FCC indoor mask [60].

Hence UWB pulses *s(t)* can be generated by filtering.

$$\lambda s(t) = \int_{-\infty}^{\infty} s(\tau) h(t-\tau) d\tau \tag{4.24}$$

where λ is an attenuation factor.

A time-limited pulse $p(t)$ is to be designed

$$s(t) = 0 \qquad |t| > T_m / 2 \tag{4.25}$$

where T_m is the time duration of UWB pulse.

Sampling is done at a rate of N samples per pulse period T_m, equation (4.23) is expressed as follows:

$$\lambda s[n] = \sum_{m=-N/2}^{N/2} s(m) h(n-m) \ , \ n = \text{-}N/2 \, ... N/2 \tag{4.26}$$

where n and m are integer values. Equation (4.26) is expressed in vector form

$$\lambda s = Hs \tag{4.27}$$

where vector s represents the discretized UWB pulse, H is a real Hermitian Toeplitz matrix or known as constant diagonal matrix given by (4.28). s is an eigenvector of H and λ is the eigenvalue.

$$H = \begin{pmatrix} h[0] & h[-1] \text{ .... } h[-N] \\ h[-1] & h[0] \text{ ....} h[-N+1] \\ \text{..} \\ h[N] & h[N-1] \text{ ....} h[0] \end{pmatrix} \tag{4.28}$$

The frequency spectrum and power spectral density (PSD) of the UWB pulse can be calculated by

$$S(f) = \frac{T_m}{N} \sum_{n=-N/2}^{N/2} s(n) e^{-j2\pi f \frac{nT_m}{N}} \tag{4.29}$$

$$PSD(f) = |S(f)|^2 \tag{4.30}$$

We require to form a zero point of the PSD of UWB pulse at the centre frequency f_0 as the major power of the interferer is concentrated on f_0. Accordingly, the desired pulse and the power spectral density (PSD) of the pulse are shown in Fig. 4.3.

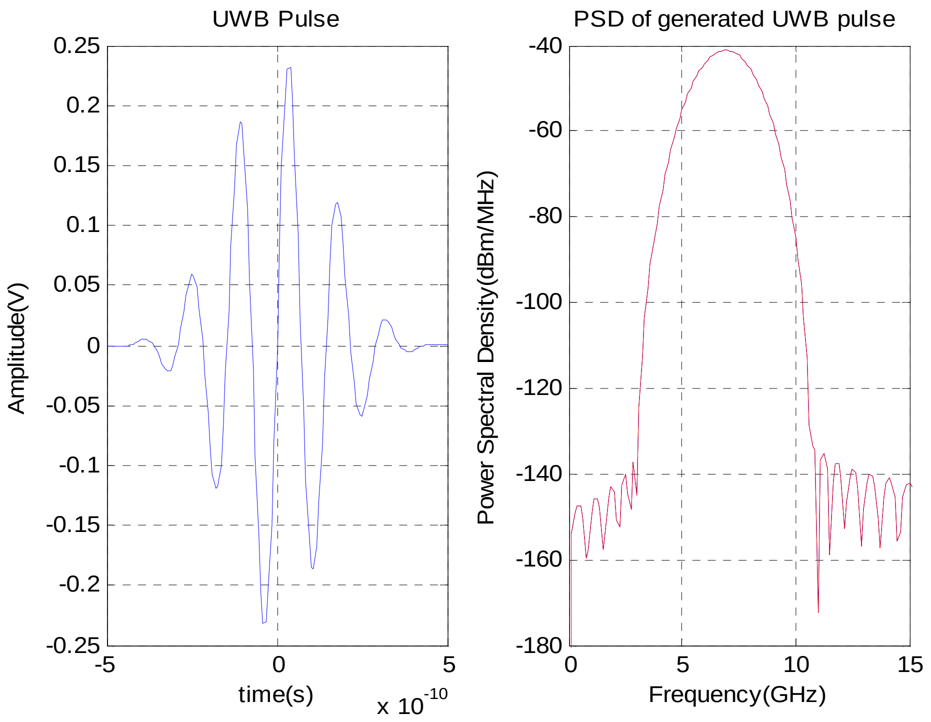

Fig. 4.3 UWB pulse and PSD generated from Eigenvalue decomposition model

4.4.1.1 Single NBI Interference Avoidance

- Following steps are involved in this method. The UWB band is divided into two bands: (f_L, f_M) and (f_N, f_H) maintaining $f_N > f_M$ [65].
- The Eigenvalue decomposition generates two sub-pulses $s_1(t)$ and $s_2(t)$ used in each sub-band. $s_1(t)$ and $s_2(t)$ meet the FCC spectral mask by adjusting f_M, f_N and $S_1(f_0) = -S_2(f_0)$ is the pulse amplitude. $S_1(f_0)$ and $S_2(f_0)$ are the frequency spectrums of $s_1(t)$ and $s_2(t)$ respectively.
- The desired UWB pulse is generated by superimposing the two sub-pulses. The PSD of UWB pulse has a zero point at f_0. Fig. 4.4 shows the PSD of the UWB pulse suppressing single narrow-band interference [64].

Spectral density is reduced by about 50 dB around the interfering band using the above technique. Hence potential interference from UWB system to single NBI system is successfully mitigated.

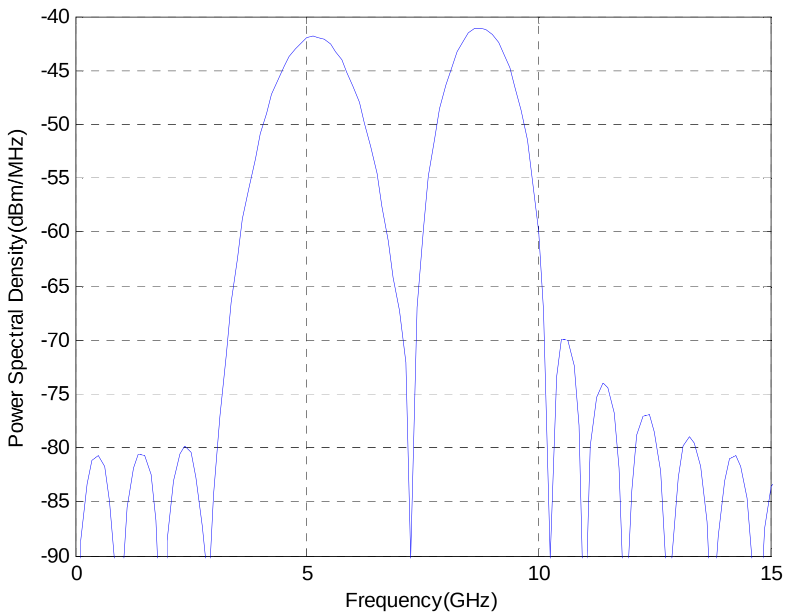

Fig. 4.4 PSD of the UWB pulse suppressing single NBI

4.4.1.2 Multiple NBI interference Avoidance

Multiple NBI narrow-band interferers are superimposed over three places in the UWB band in the simulation analysis. The lobe of the pulse becomes larger with the increment of the sub-band number from the simulation point of view. The technique is described below

- UWB band is partitioned into two bands: (f_L, f_M) and (f_M, f_H). Using the Eigenvalue decomposition method two pulse $s_1(t)$, $s_2(t)$ are generated. The narrowband interferences is assumed to be located in the lower band (f_L, f_M). So at the receiver, $s_1(t)$ should be further processed to mitigate the narrow-band interferences.
- The desired pulse is obtained from $s(t) = s_1(t) + s_2(t)$. Fig. 4.5 shows the waveform and depicts the PSD of the generated pulse.
- At the receiver, we have used a doublet pulse consisting of two received pulses $s_1(t)$ with opposite amplitudes and separated from each other by T_g time [36]. T_g represents the delay time. The processed pulse $s_d(t)$ can be expressed as:

$$s_d(t) = \frac{1}{\sqrt{2}}\left(s_1(t) - s_1(t - T_g)\right) \tag{4.31}$$

The spectral amplitude of such a pulse can be computed as:

$$\left|S_d(f)\right|^2 = 2\left|S_1(f)\right|^2 \sin^2(\pi f \, T_g) \tag{4.32}$$

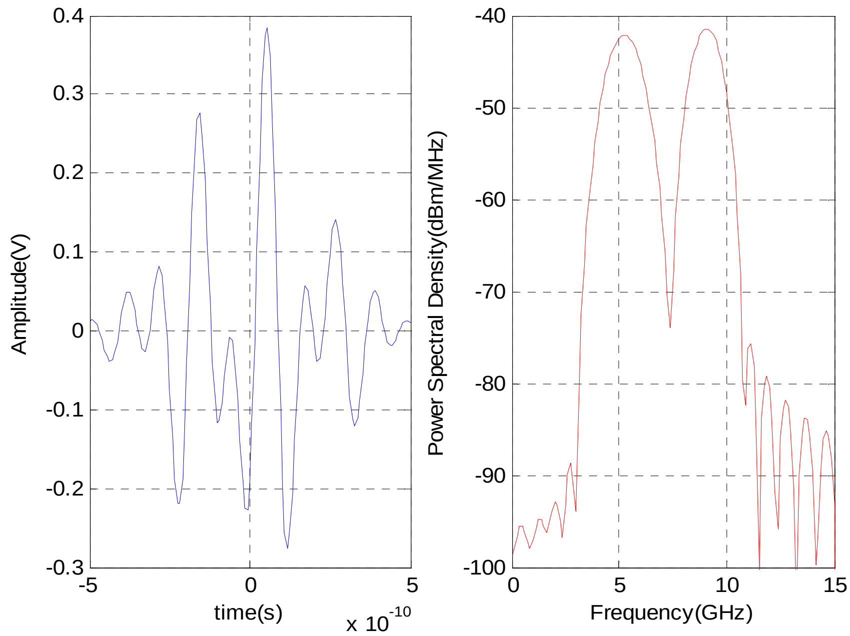

Fig. 4.5 Combination of two sub-band pulses and PSD of combination of two sub-band pulses

Spectrum of the designed pulse has nulls at frequencies at $f = kT_g$ for any integer k. T_g can be adjusted for removing the interferences in the lower band. Spectral density is reduced by more than 30 dB and hence the potential interference from UWB system to multiple NBI system can be successfully reduced.

4.4.1.3 Wideband interference Avoidance

UWB systems can coexist with several narrow-band devices and wide-band devices simultaneously. In such circumstances, the UWB band is divided into three sub-bands, having the interference bandwidth from f_{IL} to f_{IH}, which is located in the middle of UWB band. The wide-band systems employ the multiple carriers and the main transmitted power is concentrated on the carriers. So our main aim is to generate nulls at each frequency of the carrier. The difference between this mode and two sub-bands mode is the delay time T_g that could be longer according to the frequency intervals of the carriers. Therefore the wide-band interference can be mitigated successfully. This technique is discussed below

- The UWB band is partitioned into three sub-bands: (f_L, f_{IL}), (f_{IL}, f_{IH}), and (f_{IH}, f_H). Then using the Eigenvalue decomposition method three sub-pulses $s_1(t)$, $s_2(t)$, and $s_3(t)$ are generated in each sub-band respectively. As $s_2(t)$ is in the interference bandwidth so at the receiver end, it can't be used before further processing.
- A new pulse $s(t)$ with $s_1(t)$, $s_2(t)$, $s_3(t)$ is generated as

$$s(t) = s_1(t) + s_d(t) + s_3(t) \tag{4.33}$$

Its spectrum is given by

$$S(f) = S_1(f) + S_d(f) + S_3(f) \tag{4.34}$$

- The received pulse in middle band $s_2(t)$ is processed in the same way based on the method proposed in the previous section. The processed pulse $s_d(t)$ can be expressed as:

$$s_d(t) = (\sqrt{1/2})\,(s_2(t) - s_2(t - Tg)) \tag{4.35}$$

The spectral amplitude of this pulse can be written as

$$|S_d(f)|^2 = 2|S_2(f)|^2 \sin^2(\pi f Tg) \tag{4.36}$$

The PSD of the processed pulse in the middle band as shown in Fig. 4.6, the spectrum has nulls at frequencies at $f = k\ T_g$ for any integer k. Suppose the wide-band system utilizes N carriers, and the frequency interval between two carriers is F_I. Therefore, we can remove all the interference on every carrier by setting $T_g = 1/F_I$.

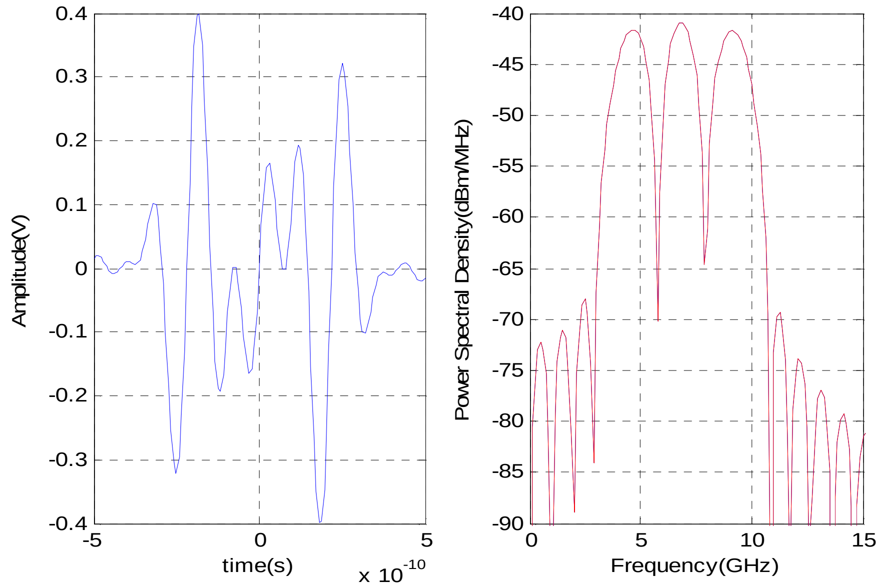

Fig. 4.6 Combination of three sub-pulses and PSD of the combination of three sub-pulses

Thus the potential interference from UWB system to wideband interference system can be successfully mitigated. Spectral density is reduced by about 30 dB at lower band and nearly 25 dB at higher band around the interfering band.

4.4.2 MODIFIED TR-UWB RECEIVER

Modified TR-UWB receiver is suggested for interference reduction from other narrowband and wideband systems to UWB systems. Severe interference saturates an unprotected UWB receiver front-end [43, 59, and 67]. Overlaying of UWB system in existing WPAN environment causes interference. This interference degrades the performance of the TR-UWB system [31]. Interference suppression in the TR receiver is proposed by eliminating the interfering band by a notch filter. Notch filter effectively cancels out the interfering band. Notch filter has been implemented with filter order of 400 and operates around 5.25 GHz [49].

From previous section x_{ii} in equation (4.17) can be effectively suppressed but the performance degradation occurs due to the remaining term $x_{gi} + x_{ni}$. The exact knowledge of the interferer frequency f_i could provide minimization of equation (4.16). So that x_{gi} can be minimized implementing accurate delay lines such as delay must be smaller than $1/f_i$ for minimization of x_{gi}.The extra term x_{ni} could be suppressed by positioning a notch filter around the carrier frequency of the interferer signal which provides a loss of significant portion of the desired signal along with interference [66, 67]. The best way to suppress the extra term by cancelling the $i(t)$ before operating the correlation between received and delay signal. To minimize the suppression of useful signal considering the bandwidth of the notch filter W_{N} and thus the remaining bandwidth of the UWB signal is $W - W_{\mathrm{N}}$.

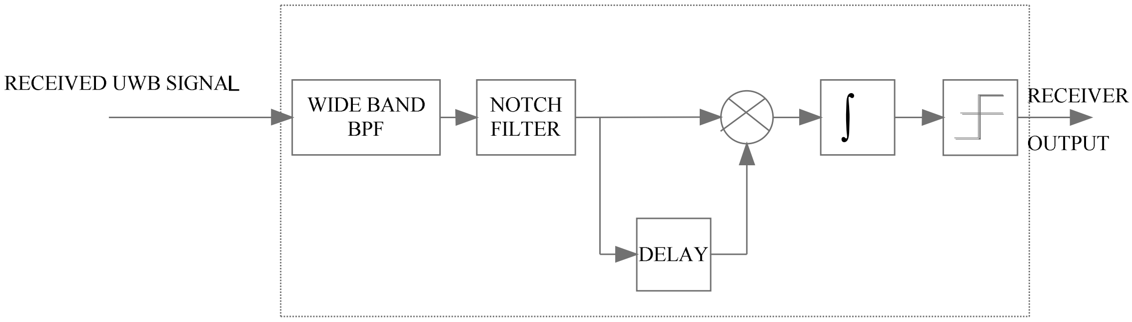

Fig. 4.7 Modified TR-UWB AcR Receiver Model

Considering the channel $h_{UWB}(t)$,the probability of error of the TR-UWB with a notch filter of W_{N} replaced by $W - W_{\mathrm{N}}$ and ϕ by $\phi \frac{W - W_{\mathrm{N}}}{W}$, which provides a uniform distribution of the signal energy over the entire bandwidth. So,

$$\mathrm{P}(e) = Q\sqrt{\frac{W - W_{\mathrm{N}}}{W} \frac{\phi^2}{\sigma_n^2}} = Q\sqrt{SNR_{W - W_{\mathrm{N}}}} \tag{4.37}$$

where, $\frac{W-W_{\mathrm{N}}}{W}$ represents scaling term. Comparing the equation (4.37) with the argument of Q function in equation (4.38) with $x_{ii}=0$. We obtain a bandwidth of TR-UWB system with notch filter

$$W_{\mathrm{N}} < W\frac{\sigma_x{}^2}{\sigma_x^2+\sigma_n^2} \tag{4.38}$$

This provides a better performance than corresponding receiver without notch filter. Considering $\int g^2(t)\,dt=1$ true for both single path channel and multipath channel, the useful signal energy becomes $\phi = E_s/2$

$$\mathrm{I}_\beta > \frac{N_0W}{2}\frac{W_{\mathrm{N}}}{W-W_{\mathrm{N}}} \tag{4.39}$$

The right side of the equation (4.39) provides the level of interference for which the received signal is filtered effectively.

4.5 PERFORMANCE STUDY OF PROPOSED INTERFERENCE REDUCTION TECHNIQUES FOR TR-UWB COMMUNICATION SYSTEM

The modified TR-UWB receiver model is studied using MATLAB. The block diagram of simulation model is presented in Fig. 4.8. Transmitted pulse is generated by pulse shaping the Gaussian doublet pulse. In the performance analysis, first AWGN channel model is used and then UWB channel model is investigated. The central frequency and the bandwidth for both single NBI and multiple NBI are set to be 5.25 GHz and 200 MHz respectively. Whereas for WBI, the central frequency is 7.5 GHz and the bandwidth is 400 MHz. UWB operates at FCC part 15 limit of -41.3dBm/MHz and interference transmitted power is 100mW. When two transmitters experience same attenuation, the signal to interference ratio (SIR) is -20dB.

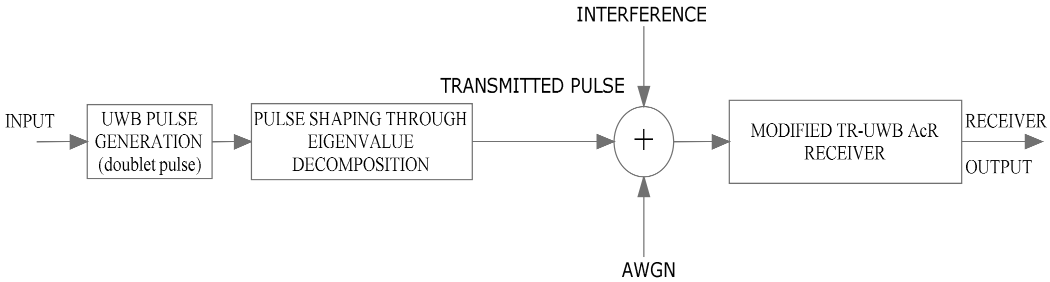

Fig. 4.8 Block diagram for simulation model

TR-UWB receiver module retrieves the transmitted data from the received signal. Wide band pass Filter (wide-BPF) at receiver frontend removes noise, which is out of band and effectively turns off the interfering band. The output from the auto-correlation is fed into a threshold device. This UWB system is operating at data rate of 12.5 Mbps. From Fig. 4.9, it is observed that the simulated conventional AcR receiver model's performance is closer to the theoretical optimum for AWGN channel model, its performance degrades. 6dB SNR degradation at 10^{-2} BER floor is observed due to interference effect. Therefore, the conventional TR-UWB receiver fails to mitigate NBI.

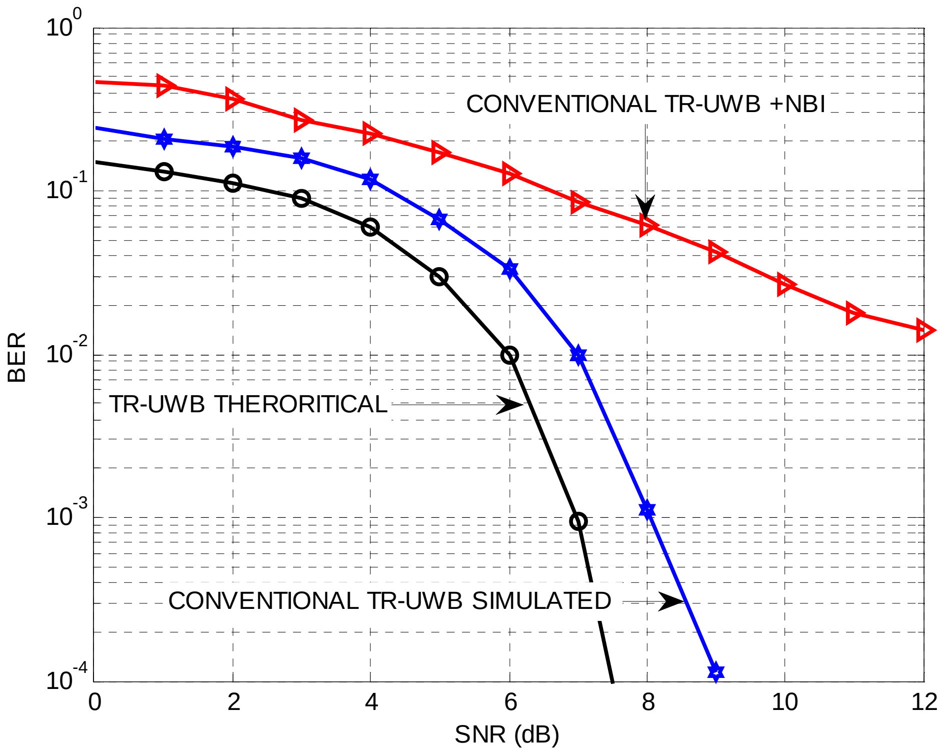

Fig. 4.9 BER performance of conventional TR-UWB AcR receiver in presence of single NBI

Fig. 4.10 illustrates that the modified TR-UWB AcR receiver can mitigate NBI and its performance is closer to the theoretical TR-UWB. Further, the effect of strong interferers like multiple NBI and wideband is investigated and found that modified outperforms the conventional one and can mitigate those interference successfully.

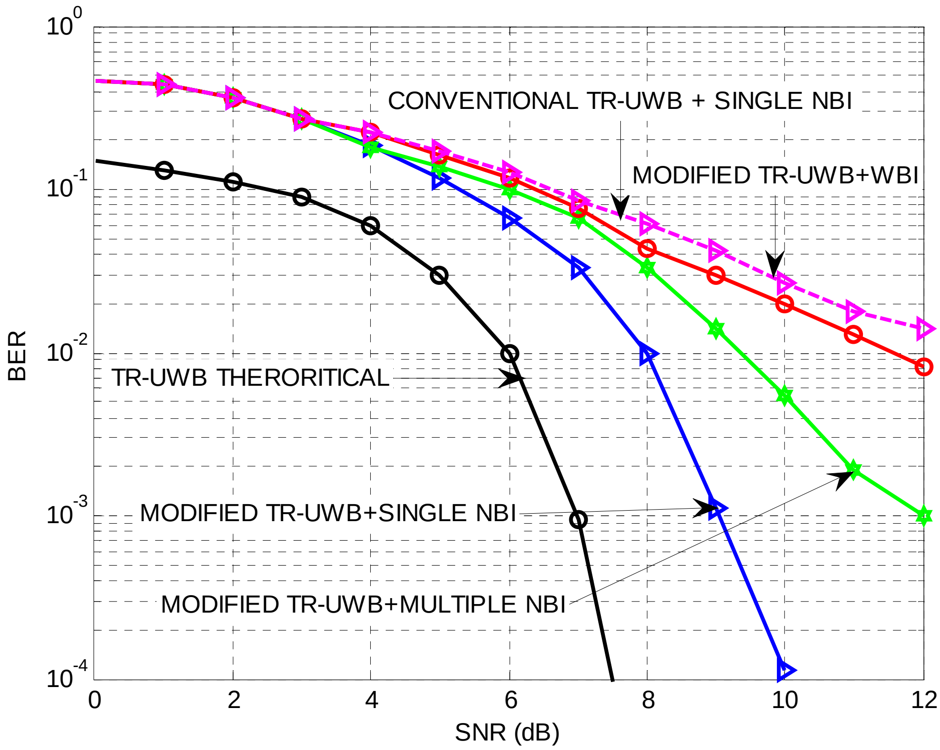

Fig. 4.10 BER performance for different interference signal along with modified TR-UWB receiver

Simulations study is done for evaluating the conventional TR-UWB system's performance in UWB channel (IEEE 802.15.3a). Fig. 4.11 illustrates BER performance comparison theoretical and simulated conventional TR-UWB with AcR receiver considering UWB channel models CM1, CM2, CM3 and CM4 based on different propagation environment. The performance of simulated conventional receiver is closer to the theoretical one. Effect of interference on UWB system using the AcR receiver model is investigated. Fig. 4.12 shows that the performance degrades due to the addition of single NBI. Thus new techniques are suggested to improve its performance. So the modified AcR receiver is proposed to mitigate interference and improve the BER performance of TR system.

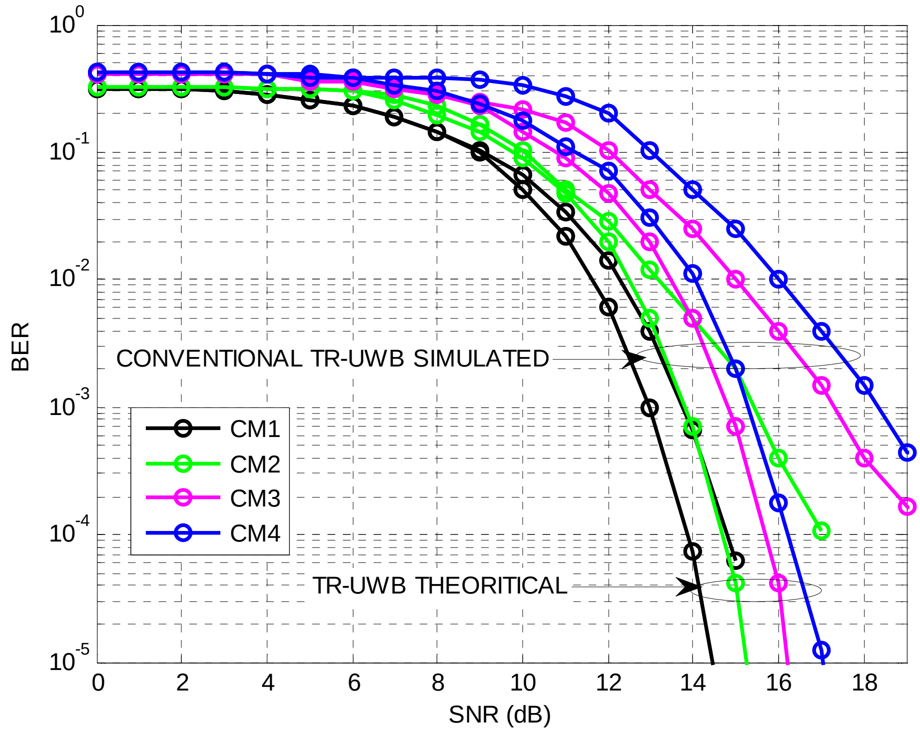

Fig. 4.11 BER performance of conventional TR-UWB AcR receiver

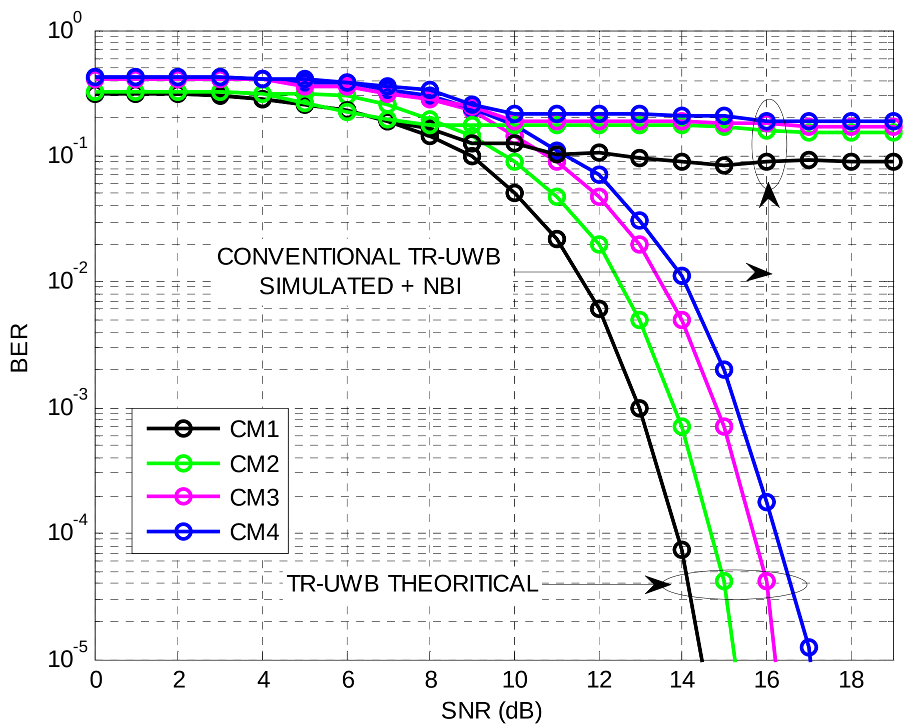

Fig. 4.12 BER performance conventional TR-UWB system in presence of single NBI

The proposed technique of pulse shape design at transmitter to cancel out the interference band and further notch filtering at receiver's end provides a suitable solution to this problem in both LOS and NLOS channel model. Further, the robustness of the modified AcR receiver is tested by incorporating strong interference like multiple narrowband and wideband. Fig. 4.13, Fig. 4.14 and Fig. 4.15 illustrates the simulated results in presence of single NBI, multiple NBI and WBI respectively. BER performance in case single NBI is closer to the theoretical optimum. But with increase in intensity of interferers, performance level deteriorates and become worst in presence of wideband interferers. Table 4.1 indicates BER performance comparisons for SNR value 14dB. Further, the modified TR-UWB AcR receiver outperforms the conventional one in improving BER by mitigating interference for UWB channel models CM1 to CM4.

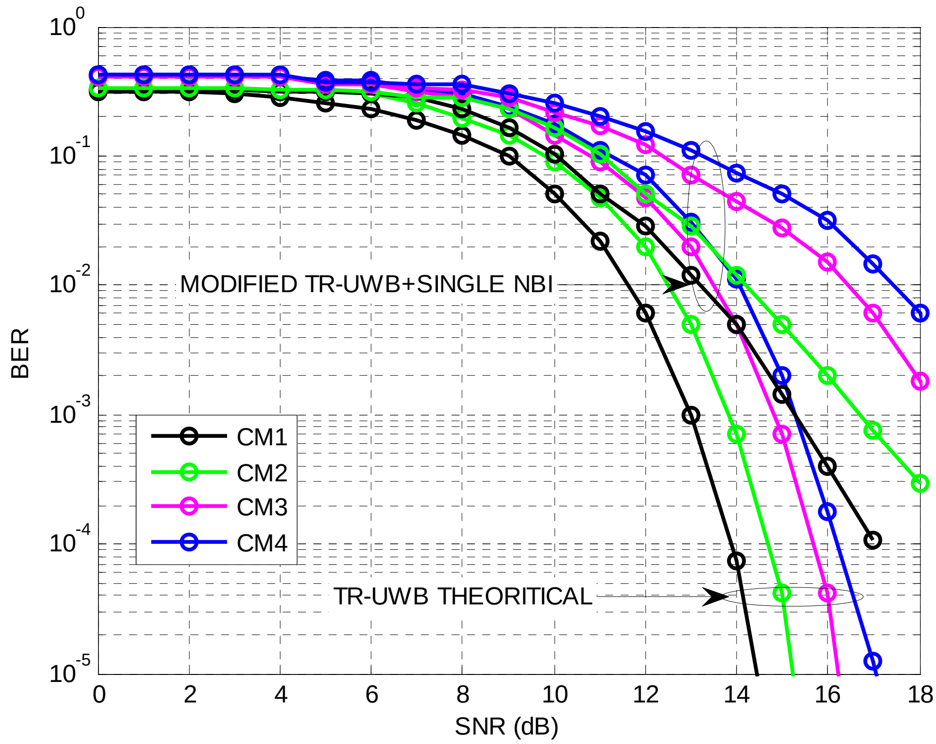

Fig. 4.13 BER performance of modified TR-UWB system in presence of single NBI

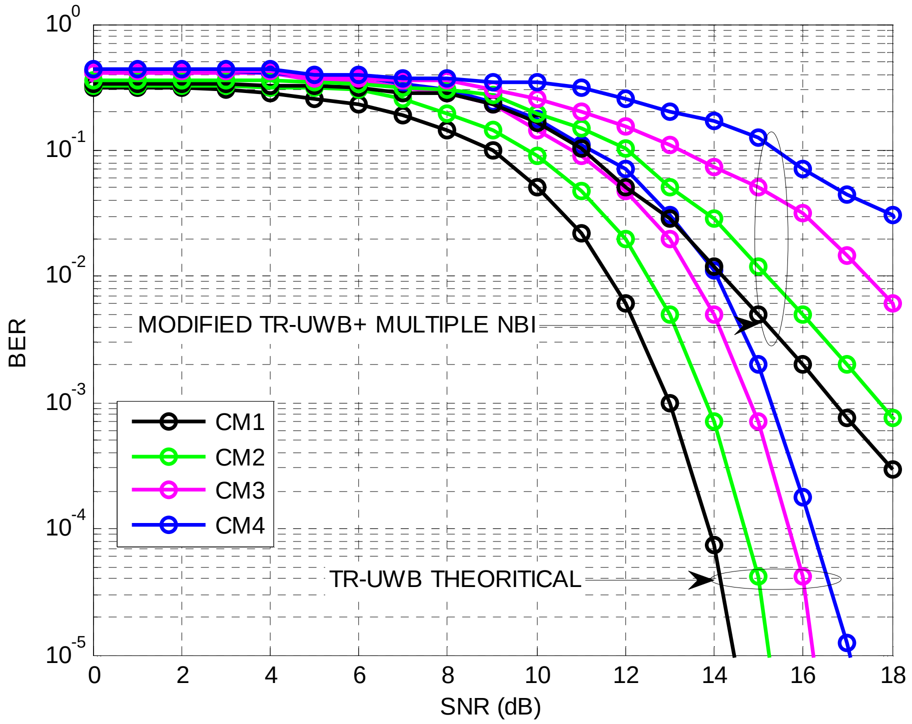

Fig. 4.14 BER performance of modified TR-UWB in presence of multiple NBI

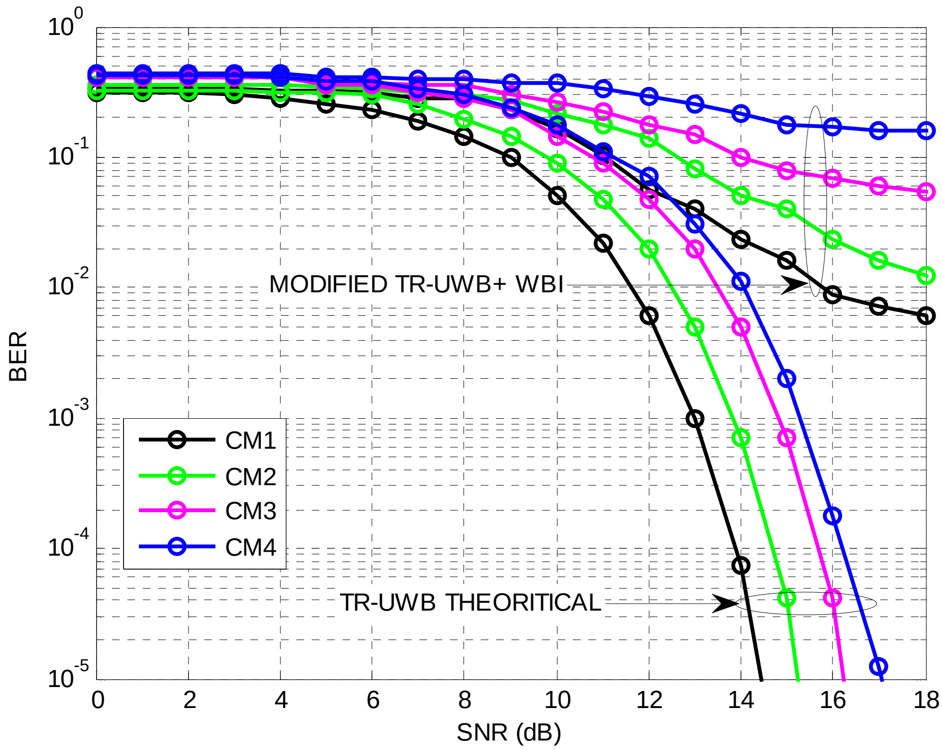

Fig. 4.15 BER performance of modified TR-UWB in presence of WBI

Table 4.1 Comparison of performance at SNR=14dB

UWB Channel models / Receiver Model Type	CM1	CM2	CM3	CM4
	BER	BER	BER	BER
Theoretical	0.7×10^{-4}	0.8×10^{-3}	0.5×10^{-2}	0.12×10^{-1}
Conventional TR-UWB receiver	0.6×10^{-3}	0.5×10^{-2}	0.24×10^{-1}	0.53×10^{-1}
Modified TR-UWB and single NBI	0.5×10^{-2}	0.12×10^{-1}	0.46×10^{-1}	0.78×10^{-1}
Modified TR-UWB and multiple NBI	0.12×10^{-1}	0.28×10^{-1}	0.72×10^{-1}	0.16×10^{-0}
Modified TR-UWB and WBI	0.23×10^{-1}	0.5×10^{-1}	0.1×10^{-0}	0.22×10^{-0}

Higher data rate for wireless is mainly restricted by ISI caused by the multipath effect of the channel. The main drawback of a TR system is the noisy template used for detection. In the presence of ISI, the template suffers from the overlapping of the earlier transmitted pulses via multipath, thereby limiting the performance of the system.

The data rate R for TR-UWB system is defined by

$$R = \frac{1}{N_s T_f} \tag{4.40}$$

where $T_f=2(T_d+T_p)$. T_f is the frame time, and T_d is the delay between two pulses in a frame which for a non ISI case is greater than the multipath delay spread time T_{mds}. and T_p and T_f are known as pulse duration and frame time respectively. Therefore, ISI increases as the data rate increases. Simulations study is carried out to evaluate the ISI effect is the modified TR-UWB AcR receiver. Performance curves are obtained by varying the data rate from 10Mbps to 125Mbps. N_s is the number of times the pulse is transmitted to capture adequate energy for detection. By taking N_s = 1, T_p = 1 ns and T_d = 39 ns, data rate is calculated as R = 12.5 Mbps. Similarly, data rates 10 Mbps and 125 Mbps can be maintained.

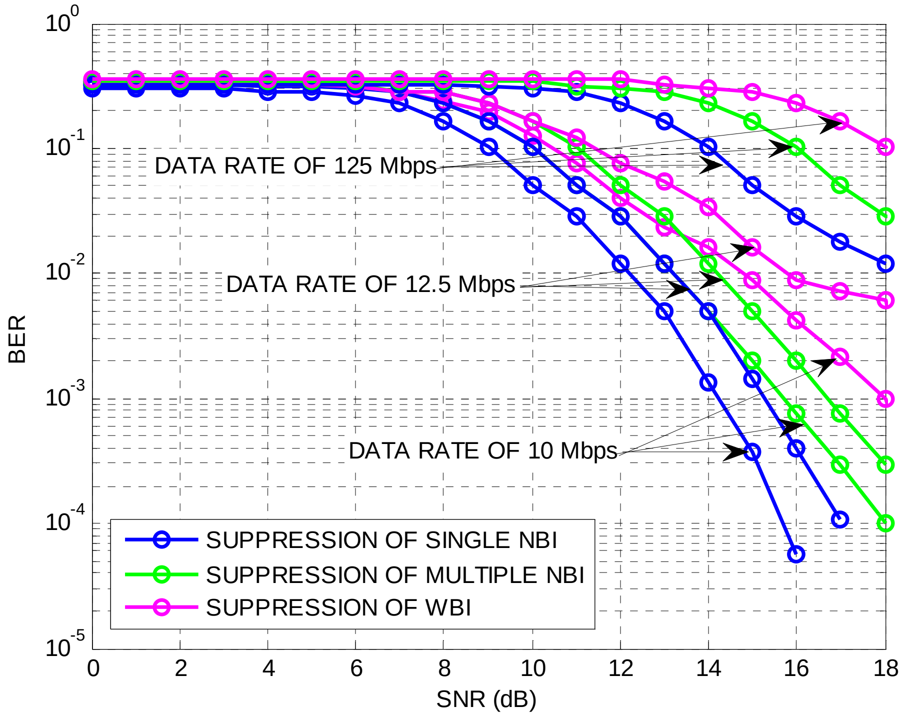

Fig. 4.16 Suppression of Interference using different data rate for CM1 channel model

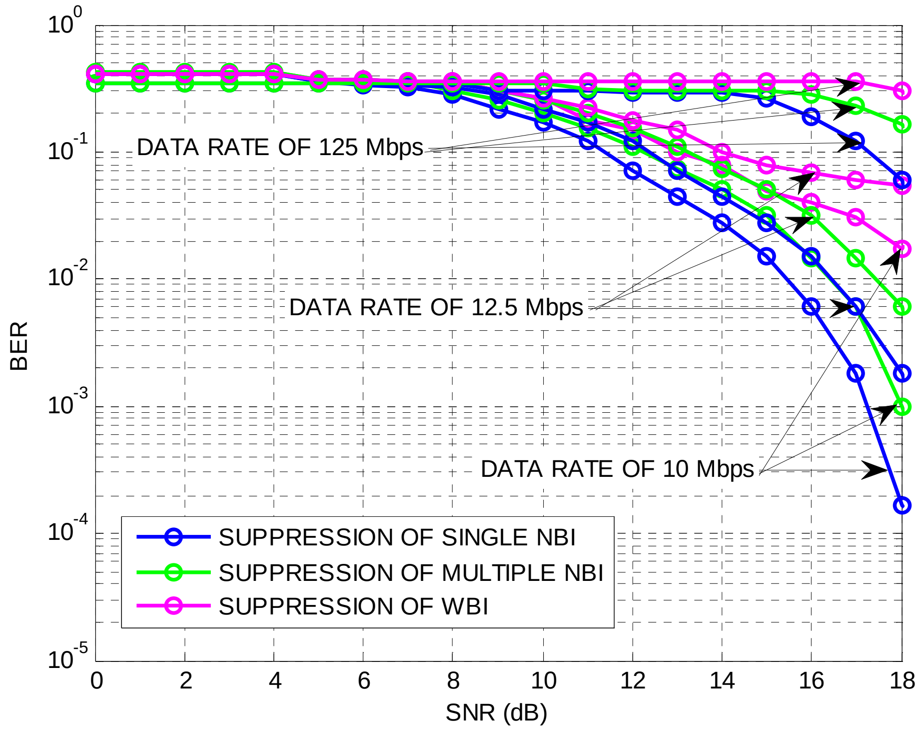

Fig. 4.17 Suppression of Interference using different data rate for CM3 channel model

Fig. 4.16 and Fig. 4.17, describes the performance of modified AcR receiver in presence of single NBI, multiple NBI and WBI increasing the data rate from 10Mbps to 125 Mbps in CM1 and CM3 channel models. The modified TR-UWB AcR receiver is able to mitigate single NBI and multiple NBI interference efficiently for data rates 10 Mbps, 12.5 Mbps and at a high data rate of 125Mbps. However, suppression of wideband interference becomes difficult as indicated by almost flat BER floor, which is more prominent in NLOS CM3 channel model case where ISI is prevalent.

4.6 CONCLUSION

Interference mitigation from UWB to other system by using Eigenvalue decomposition pulse design technique has some advantages such as the pulses meets FCC spectral mask, occupies a short duration and easy to implement. TR-UWB system performance is studied extensively in the presence of a strong NBI and WBI interference. Interference from TR-UWB is reduced by the energy in overlapping bands by using multicarrier based transmission pulses. Spectral density of the transmitted UWB signal around the interfering band is reduced than the peak. From the study of interference effects in TR-UWB system using AWGN channel model it is concluded that conventional AcR receiver cannot suppress NBI where as the modified AcR receiver is able to mitigate by notch filtering the signal at the front-end of TR-UWB. BER performance level is closer to the theoretical TR-UWB system. Robustness of modified one is further verified by introducing multiple NBI and wideband interferences to the UWB channel. At low data rate of 10 Mbps system performance is better as the effect of ISI is negligible. At high data rate of 125 Mbps ISI affects the system and degrades the performance. Hence we can conclude that the modified receiver suppress the interference up to 125 Mbps data rate. As NBI suppression can be done at so high data rate, thus it can be concluded that this robust TR-UWB system provides very good technical solution to be used as UWB PHY layer for short-range high data-rate wireless applications as it can sufficiently coexist with other narrowband and wideband wireless systems. Further, the techniques adopted are very simple from design aspect.

Chapter 5

Conclusion

CONCLUSION

5.1 Introduction

A new promising technique is adopted by 4G community is ultra-wideband technology which offers a solution for high bandwidth, high data rate, low cost, low power consumption, position location capability, resilience to multipath fading etc. But due to regulation by FCC emission mask, UWB coexistence in WPAN environment become a sensitive issue and interference to other narrowband systems is of primary concern. Although, the pulse design methods meet FCC spectral mask properly and well suppress the single narrowband interference, but unable to suppress strong interferences like the multiple narrowband interference and wideband interference. A conventional type of UWB communication is impulse radio, where very short transient pulses are transmitted rather than a modulated carrier. Consequently, the spectrum is spread over several GHz, complying with the definition of UWB. Currently, the Rake receiver used for spread spectrum is considered to be a very promising candidate for UWB reception, due to its capability of collecting multipath components. However, perfect synchronization can never be accomplished. Another issue is the matching of the template with the received pulse. Moreover, often number of rake fingers required to accommodate the wireless channel is more, rendering it unfavorable from implementation point of view. However, the Transmitted Reference (TR) signaling scheme does not suffer from the aforementioned problems and requires fewer RF building blocks compared to the multiple finger Rake receiver. The core part of the transmitted reference scheme is known as autocorrelation receiver.

The thesis begins with an introduction to Ultra Wideband technology with its application, advantages and disadvantages. Design of UWB short pulse and a detail study IEEE 802.15.3a UWB channel models statistical characteristics have been analyzed through simulation. In this research work, simulation studies are performed and improved techniques are suggested for interference reduction in both Impulse Radio based UWB and Transmitted Reference UWB system. Modified TR-UWB receiver with UWB pulse design at transmitter end and notch filtering at receiver's front end proved to be more efficient than other conventional IR-UWB RAKE-MMSE for single NBI, multiple NBI and WBI suppression. Extensive simulation studies to support the efficacy of the proposed schemes are carried out in the MATLAB environment. Bit error rate (BER) performance study for different data rates over different UWB channel models are also analyzed using proposed receiver models. Performance improvement of TR-UWB system is noticed using the proposed techniques.

Following this introduction, section 5.2 summarizes the main contribution of this thesis. Section 5.3 provides the scope of further research work in this field.

5.2 Contributions of Thesis

- Chapter-1 provides the overview of the developments and technological aspects of UWB communication system. It also presents the motivation for this research and outline of the thesis.
- In Chapter 2, the definition and the basic concepts of UWB communication technique are discussed. Advantages and major limitations like interference with other wireless systems are explained. The UWB pulse design using Gaussian pulse in both time and frequency domain is presented. Major statistical characteristics are investigated considering wireless indoor UWB channel models based on IEEE 802.15.3a standard.
- Chapter-3 investigates the Impulse Radio UWB technology and its interference effects due to coexistence with narrowband wireless systems like blue tooth and WLAN etc. Previously reported schemes Rake receiver with different multipath diversity technique is applied and through simulation study it is found that UWB SRake outperforms the other types. Nevertheless, UWB SRake receiver fails to perform satisfactorily in presence of narrowband interference. So MMSE combining is used at receiver's end of SRake receiver it is a simple technique, as it does not require any explicit knowledge of interference. UWB SRAKE-MMSE receiver in IR-UWB system also reduces ISI and improves BER performance. By

optimally combining the number of equalizer taps and number of rake fingers performance of UWB SRAKE-MMSE can be further enhanced. It is also notified that a decision feedback type structure performs better than linear equalizer. NBI cancellation by SRAKE-MMSE receiver using CM1 (LOS), CM2 (NLOS), CM3 (NLOS) and CM4 (NLOS) wireless indoor channel model is analysed through simulation study. SRAKE-MMSE can easily suppress the interference by taking the benefits of rake fingers and equalizer taps. But the major drawbacks of this method are channel estimation for IEEE UWB channel models is complicated as large number of rake finger and equalizer taps are required for improving performance level. Also in high data rate UWB system, orthogonality between each of signals in various rake fingers is an invalid assumption, which leads to inter symbol interference.

- In Chapter-4, Transmitted reference signaling scheme is introduced to overcome the limitations of previously mentioned IR based UWB. In this research, an efficient interference mitigation technique using pulse design and modified TR-UWB approach are proposed. TR-UWB receivers are popular for their simplicity, capability to reduce the strongest UWB timing requirements and robust performance in multipath channels. TR-UWB system are susceptible to other interference because the interference will be multiplied at the AcR receiver's end. Therefore, this system needs improvement to coexist with narrowband interference. Designed UWB pulses using Eigenvalue decomposition method meets FCC spectral mask, occupies a short duration and easy to implement. Then a modified TR-UWB receiver model is introduced with the transmission of designed UWB pulses and eliminating the interfering band by a notch filter at receiver's front end. Robustness of modified one is further verified by adding multiple NBI and wideband interferences to indoor wireless channel model from BER performance through extensive simulation studies. At low data rate of 10 Mbps system performance is better as the effect of ISI is negligible. At high data rate of 125 Mbps, ISI affect the system and performance degrades. NBI suppression is possible at high data rate by the proposed technique. The suggested technique is simple to design and easy to implement. Hence coexistence of UWB devices with other NB systems will not pose any serious problem during implementation in WPAN environment.

5.3 Scope of Further Research

By concluding this thesis, the following are some pointers for scope of further research.

- The proposed interference suppression techniques can be extended for multiband-OFDM (MB-OFDM) UWB system, which will be of prime importance for 4G applications.
- Wavelet based pulse shape design method may be attempted.

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Dissemination of Work

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